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ENGINEERING CONTROLS TO REDUCE HYDROGEN SULPHIDE (H2S) EXPOSURE OF WORKERS IN SWINE BUILDINGS

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PRAIRIE SWINE CENTRE INC.

FINAL REPORT

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Saskatoon, Saskatchewan
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Engineering Controls to Reduce Hydrogen Sulphide Exposure of Workers in Swine Buildings – Final Report

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■ Summary

Three engineering controls were developed and evaluated for effectiveness in protecting swine barn workers from exposure to hydrogen sulphide (H_2S). A remote manure pit plug pulling system allowed pulling of the manure pit plug from outside the room, thereby eliminating risk of worker exposure to H_2S. A water sprinkling method resulted in 79% reduction of H_2S concentration under optimal laboratory conditions. Additional work needs to be done to assess its effectiveness on reducing H_2S from agitated manure. A manure scraper system used to remove manure daily reduced H_2S levels by 80 to 96% compared to a normal production room. However, ammonia emissions in the scraper room were about 36 % higher.

■ Background

Hydrogen sulphide is a life threatening gas produced by the anaerobic degradation of liquid manure. Most of the H_2S produced by anaerobic bacteria in manure pits remains dissolved in the liquid manure as long as the manure is not agitated. The molecular weight of H_2S (34.08 kg/kmol) is greater than that of air (28.96 kg/kmol), which means that H_2S emitted from the surface of liquid manure in a pit will tend to stratify at the surface of the manure and that considerably slows down the upward diffusion of H_2S in the air.

Results from a research project performed by the Prairie Swine Centre Inc. (PSCI) strongly suggest that workers are at risk of H_2S exposure while performing manure management tasks in the barn, such as pulling pit plugs (Chénard et al., 2003). Out of 138 plug pulling events monitored in different barn sections, 114 events (83%) generated H_2S concentrations higher than 15 ppm (STEL value: time weighted average not to be exceeded for a 15 min exposure period, Saskatchewan Occupational Health and Safety) at the worker level above the pits. Monitoring performed along manure pits during emptying also showed that the highest H_2S concentrations obtained were not always measured in the vicinity of the plug but could occur anywhere above the manure channel in the room.

An increasing number of workers on specialized pig operations now spend more time inside the barns on a continuous basis. In some cases workers may be assigned to specific tasks related to manure management that can significantly increase their exposure to H_2S (e.g. manure application contractors, workers assigned to manure management and maintenance of equipment in the barns, crews assigned to power washing and pulling manure pit plugs). Economical and practical preventative measures need to be implemented to help ensure that the H_2S levels do not reach hazardous concentrations in swine barns in order to protect the health and safety of both workers and swine. These measures will assist the swine industry in being both responsible and proactive, and will contribute toward its sustainability and expansion.

■ Project Objectives

The main goal for this project is to develop low-cost and practical techniques that can be adapted in existing swine buildings to prevent or reduce worker exposure to high H_2S concentration during manure handling. The specific objectives are:

Module 1

To design and evaluate an improved pit plug concept that will allow for pit plugs to be opened from a remote location and that will prevent pit drains from remaining open when pressure buildup in sewer lines cause pit plugs to pop open.

Module 2

To measure H_2S abatement when a water-based liquid is sprayed over swine manure when the manure is agitated (mimicking pit plug pulling events).

Module 3

To develop and evaluate a pit scraper system for manure handling that would remove swine manure from the barn on a daily basis, decreasing the H_2S exposure during handling and storage, and improving manure solids handling. The system will be developed for retrofitting in existing barns with liquid manure handling systems.

■ Module 1 - Improved Design for Pit Plugs

Background

Two undergraduate students in Agricultural and Bioresource Engineering, T. Bjarnason and M. Marshall, selected the topic of designing an improved pit plug for swine manure pits as their Design Capstone project. They began work on this project in January 2002 under the supervision of Dr. Laguë. Brainstorming sessions were conducted both at the University of Saskatchewan (U. of S.) and at PSCI in March 2002.

Objectives

The specific objectives of this module include the design and development of a pit-plug pulling system that will:

1. allow the plugs to be opened from a remote location.
2. not allow backflow of manure or gases when the plugs are closed.
3. be able to be adapted to as many existing in-barn manure management systems as possible.

Methodology

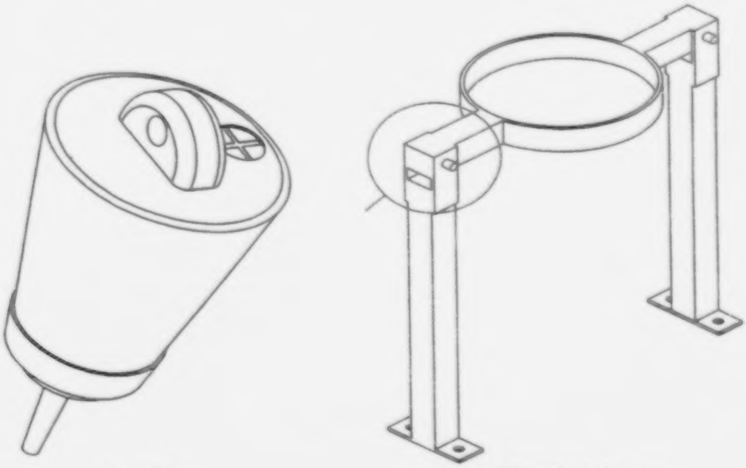
Within the scope of this module of the research study, the students, with the assistance of technical staff at U. of S. and PSCI, built a bench-scale prototype of their system. This prototype consisted of a large tank (to simulate the hydraulic head at a plug location) with a drain hole at the bottom of the same diameter than that of sewer holes in typical manure pits. Provisions for applying back pressure, using pressurized air, under the plug were incorporated in the design of the test bench. A testing program aimed at evaluating the performances of the improved plug design in terms of sealing characteristics, ease of opening and closing the sewer hole and resistance to back pressure from the sewer line was completed.

Upon completion of the testing program, the optimum system was selected and built in two grower-finisher rooms at PSCI – Floral. The system was then tested in each room by measuring the H_2S concentration using a Draeger H_2S Pac III monitor suspended 1 m above the plug area when the plugs were pulled, and a Pac III monitor was also used in the hallway to measure the H_2S concentration by the winch.

Results

Prototype Design

Several plug designs were examined, including a balloon plug, sphere plug, extended cone plug and inverted plug. The selected solution, the extended cone plug (Figure 1a), met the design criteria of low cost, ease of installation, safety, plug popping control and formation of a consistent seal. This design also minimized the flow restriction to the hole. A plug height stop was also designed to prevent the plug from coming out of the hole too far (Figure 1b). With this plug height stop in place, if the plug was pulled or if it pops due to a build-up of pressure, the funnel-shaped extension on the plug will remain in the hole and guide the plug back into the hole and re-form the seal.



(a). Plug (b). Plug height stop

Figure 1. Final design of the modified extended cone plug and the plug-height stop frame.

The initial cost, operating cost and maintenance of the plug pulling system were the criteria used to choose among an air pressure system, electric motor apparatus and pulley system. The pulley system with optional winch was selected as the preferred method of mechanical plug pulling.

A prototype of the design was tested in a 170-L barrel that simulated 0.762 m of water head. The force required to pull the plug at four different water heads was measured and, using the developed linear regression equation, the force required to pull the 10.55 kg plug at a maximum manure depth of 1.22 m was estimated to be 630 N (142 lb). The occurrence of plug popping events was tested by introducing compressed air into a pipe below the plug. Air introduced into the tube leaked around the plug, preventing pressure build-up and plug popping. From the testing and design considerations, it was felt that if the plug did pop due to pressure build-up, the plug height stop and extended cone design would immediately guide the plug back into the hole and reform the seal.

The design and testing stages were completed in December 2002. The design incorporated existing sewer lines and drainage holes in the floor of the pits, helping minimize the initial implementation costs. The pulling mechanism design allowed the two plugs in each pit to be pulled separately, allowing the worker to control which end of the manure pit is emptied.

System Testing

A prototype of the plug system was installed in two full-scale grower-finisher rooms at PSC in the spring of 2003, and its operation was tested. The pulley system with optional winch was selected as the preferred method of mechanical plug pulling (Fig. 2). A cage was also designed to prevent the plug from coming too far out of the hole (Fig. 3).

In order to pull the plug out using the winch, a cable was threaded around the winch, through a small hole in the wall and through a pulley, which was installed on the wall directly opposite the winch inside the room. This cable was then able to be used for the manure pit plug at either end of the room by attaching it to a second cable run through either a second pulley located on the pen wall just above the manure pit plug closest to the winch, or through a pulley mounted on the ceiling above the first plug, then strung through to a second pulley mounted on the ceiling directly above the second manure pit plug. Before turning the winch, the cable would be hooked up to the corresponding plug cable and the winch would then be cranked, pulling the plug out of the hole.

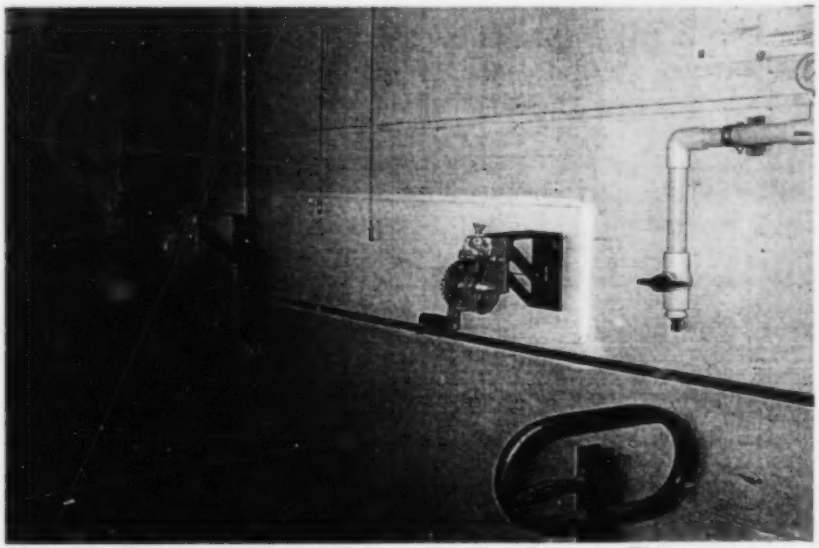


Figure 2. Pit plug pulling winch system in alleyway. There are two winches operating two separate systems in two different rooms.

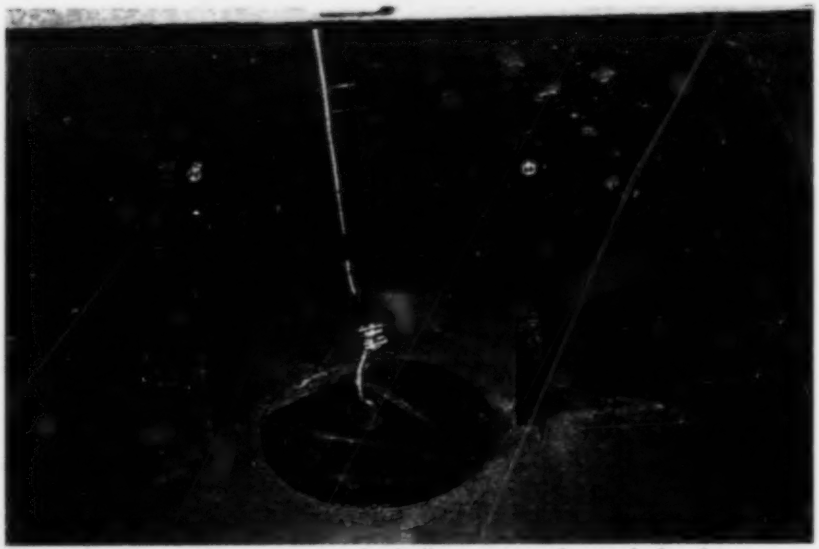


Figure 3. Plug pulling apparatus including cage underneath the slats.

Nine pulling events were recorded, with the H_2S concentration measured in both the room where the plug was pulled, and in the alleyway where the winch was located. The maximum H_2S concentration from all the monitored events was 68 ppm, with corresponding concentrations in the alleyway near the winch at 0 ppm. This indicated that the system has proven to be very effective in protecting the worker from being exposed to H_2S by allowing the plug to be pulled from outside the room, thus moving the worker outside the danger area.

The cost of building and implementing the system was calculated. The unit cost per pit was $102 with the majority of this cost being for the pulling system. The optional winch would cost an additional $40, but it could be used for multiple rooms. The cost to implement this design in a 4-plug room was estimated to be $240 ($280 with the winch).

■ Module 2 - Bench Scale Experiments on Hydrogen Sulfide Abatement by Water-Based Liquid Spraying

Part 1 – Laboratory Study

Objectives

A laboratory study was initiated to achieve the following objectives:

1. investigate the potential of sprinkling tap water as an option to reduce H_2S levels;
2. examine the use of essential oils in the sprinkled tap water to reduce H_2S levels;
3. examine the use of increasing the pH of sprinkled tap water to control H_2S levels;
4. examine the use of ferric sulfate in sprinkled tap water to control H_2S levels;
5. examine the use of hydrogen peroxide in sprinkled tap water to control H_2S levels;
6. examine the effects of sprinkled water temperature on H_2S levels; and to
7. determine optimum rates and frequencies for water sprinkling to reduce levels of H_2S.

Literature Review

Hydrogen sulphide

In an aqueous solution, H_2S gas will ionize to produce H^+ and HS^- (Arogo et al., 2000). Haimour and Sandall (1984) investigated the molecular diffusivity of H_2S in pure water at different temperatures and found that the diffusivity varied from 1.53×10^{-5} cm^2/s at 15°C to 2.32×10^{-5} cm^2/s at 35°C. When dissolved in an aqueous solution, H_2S forms a weak diprotic acid that dissociates into hydrogen ions (H^+), bisulfide (HS^-), and sulfide (S^{2-}) ions (Arogo et al., 1999). The presence of H_2S in different forms was governed by the following equilibrium equations (Chen, 1974):

$$H_2S_{(aq)} \leftrightarrow H_2S_{(g)}$$

$$H_2S_{(aq)} \leftrightarrow H^+ + HS^-;\ K_{a,1} = 10^{-7.1} \text{ at } 25^\circ C$$

$$HS^- \leftrightarrow H^+ + S^{2-};\ K_{a,2} = 10^{-14} \text{ at } 25^\circ C$$

where $K_{a,1}$ and $K_{a,2}$ are the first and second ionization constants and are mainly functions of temperature.

pH

Arogo et al. (2000) found that maintaining a pH level greater than 7 in the liquid near the surface of the manure pit will reduce H_2S release by mainly keeping it in the ionic forms. When the pH of the solution decreases, an increase of $H_2S_{(aq)}$ occurs, increasing the potential of $H_2S_{(g)}$ release. When the pH < 5, all the sulfides in the solution exist as H_2S. At pH 7, H_2S and HS^- are present in equal amounts. At pH 10, all the sulfides exist as HS^- and at pH 14 there was 50% HS^- and 50% S^{2-} (Arogo et al., 1999).

Clanton et al. (1999) studied the use of various chemicals added to swine manure to reduce H_2S in a laboratory setting, and found that hydrogen peroxide (H_2O_2) and potassium permanganate were effective in reducing H_2S gases. The hydrogen peroxide oxides the H_2S gas by the following equations:

$pH < 8.5$

$$H_2O_2 + H_2S \rightarrow S + 2\,H_2O$$

or:

$pH > 8.5$

$$4H_2O_2 + S^{=} \rightarrow SO_4^{=} + 2H_2O$$

Additionally, they comment that raising the pH of the manure by reducing the concentration of hydrogen ions converts H_2S to HS^- and/or $S^{=}$, but raising the pH also allows ammonia to volatize.

Ferric sulfate

Asai (1990) explains the process where aqueous ferric sulfate ($Fe_2(SO_4)_3$) was used as an absorbent and oxidizes H_2S to elemental sulfur and $Fe_2(SO_4)_3$ was reduced to $FeSO_4$. The reaction was as follows:

$$H_2S + Fe_2(SO_4)_3 \rightarrow S + 2FeSO_4 + H_2SO_4.$$

Methodology

Experimental approach

Preliminary work was done to investigate the effect of sprinkling water on reducing H_2S levels using different combinations of nozzles, operating water pressures and water treatments. Based on the preliminary results, an experiment was designed using the most promising treatments to determine the effectiveness of water sprinkling to reduce H_2S gas.

Material

Figures 4 and 5 depict the laboratory setup for the H_2S sprinkling system. A PVC pipe 0.9 m high with a 0.3 m diameter was used. A thick sheet of PVC was welded to the bottom of the pipe to create a seal, and the sheet extended 3" around the edge of the pipe to create a lip. To this lip legs were attached so the entire pipe rested 0.15 m from the working surface, allowing access to the underside of the pipe. The top of the PVC pipe had a ring welded as a rim at the top, which extended about 2.5 cm from the pipe. A metal ring with predrilled holes was screwed to this top ring, and a solid ring of rubber was laid across the rim with a sheet of plexiglass placed on top. The plexiglass was then siliconed and bolted to the rim of the PVC pipe to create an airtight seal.

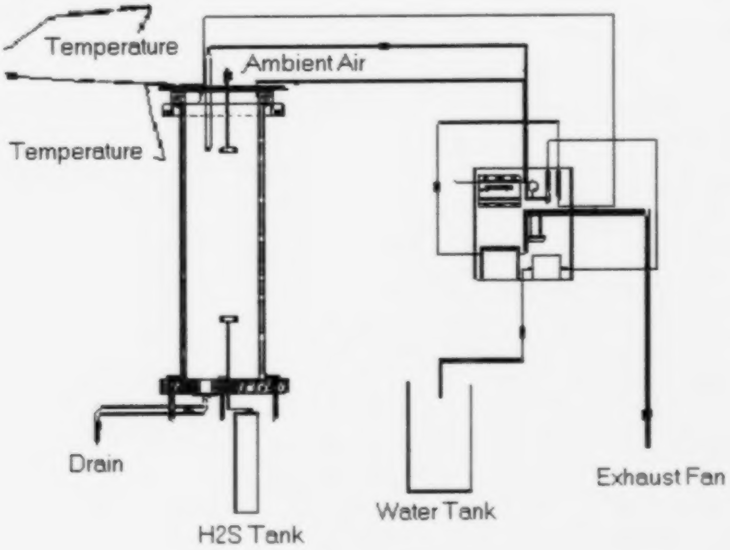


Figure 4. Overall schematic of hydrogen sulphide laboratory setup.

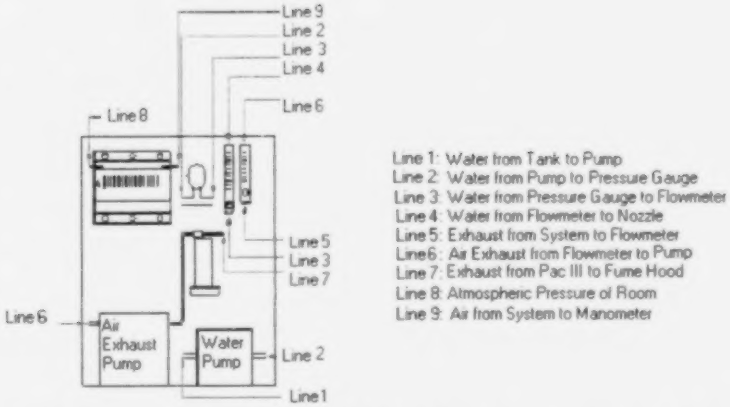

Line 9
Line 2
Line 3
Line 4
Line 8
Line 6
Line 5
Line 3
Line 7
Line 6
Air Exhaust Pump
Water Pump
Line 2
Line 1
Line 1: Water from Tank to Pump
Line 2: Water from Pump to Pressure Gauge
Line 3: Water from Pressure Gauge to Flowmeter
Line 4: Water from Flowmeter to Nozzle
Line 5: Exhaust from System to Flowmeter
Line 6: Air Exhaust from Flowmeter to Pump
Line 7: Exhaust from Pac III to Fume Hood
Line 8: Atmospheric Pressure of Room
Line 9: Air from System to Manometer

Figure 5. Diagram of hydrogen sulphide laboratory system operation.

An exhaust pump (Single head Dia-Vac, Air Dimensions Inc., Deerfield Beach, FL, USA) was connected to the exhaust outlet at the top of the pipe to draw air from the system and a flowmeter with a needle valve (Praxair, FM1000, Saskatoon, SK) at the exhaust port monitored the pump flow rate. An H_2S monitor (XS EC 1000 ppm, Dräger, Lübeck, Germany; reproducibility of 5%) was used to measure the H_2S concentration in the exhaust airflow. The calibration connections used for the Pac III were utilized in this system to enable the Pac III to read the H_2S in the exhaust air. The tubing from the exhaust air was then run outside the laboratory. The Pac III was downloaded after each use to observe the patterns of gas emitted from the system.

A 550 L tank of 1000 ppm H_2S gas (Praxair, Saskatoon, SK) was used to supply gas into the system. A regulator and rotameter (FM1000 Rotameter, Praxair, Saskatoon, SK) controlled the flowrate of the gas into the pipe. A manifold for the H_2S gas was designed that ensured an even pressure drop of gas into the system, allowing for an even distribution of the H_2S gas inside the pipe at 0.3 m from the bottom of the pipe. The manifold design also ensured that water did not enter the gas inlet lines at the bottom of the tank.

The head space of the tank was ventilated so by injecting a known amount of H_2S in the tank, it was possible to recreate an H_2S concentration pattern at the tank air exhaust similar to what was observed in barn conditions during the Chénard et al. (2003) study. An air inlet was provided in the PVC pipe, and a manometer was used to monitor the pressure difference across the tank during the experiments to ensure that the air inlet does not ultimately act as an exhaust port. As well, the air inlet had a similar manifold to the H_2S gas inlet to ensure an even distribution of the inlet air into the pipe.

A 19-L tank was used to supply water to the system and a small diaphragm pump (Bypass Diaphragm Pump, Labcor, Anjou, QC) was used to draw water from the tank and into the pipe. Use of the tank allowed products to be added to the water to test the effect of different liquids on reducing H_2S, including buffer solutions to change the pH and adding hydrogen peroxide to the water. Initially, two different nozzles were tested, one which distributed a full-cone spray (1/4 T-D1.5-31 UniJet Series Spray Nozzle, John Brooks Company Ltd., Winnipeg, MB), and one which distributed a hollow-cone spray (1/8 A-0.5 WhirlJet Series Spray Nozzle, John Brooks Company Ltd., Winnipeg, MB). The full cone nozzle distributed larger droplets at 0.38-0.87 L/min from 70-400 kPa (10-60 psi) for one nozzle, and the hollow cone spray nozzle distributed fine water droplets at 0.19-0.42 L/min from 70-400 kPa. Different water inlet pressures will change the capacity of the nozzles, and different inlet pressures were investigated using a pressure gauge

(2.5" Industrial Gauge, Labcor, Angou, QC) and a flowmeter with a needle valve (Muis Controls, Rotameter, FR2000 and FR4000 series, Edmonton, AB) to change the flow rates. The water was drained from the bottom of the tank after each trial, which then flowed to an enclosed water tank.

Temperature measurements (type T thermocouple, ±0.5°C) inside the tank, inside the laboratory and inside the water-sprinkling tan'. were measured and recorded on a datalogger. All tubes and wiring entering the setup were siliconed at their entry points to the system to ensure no H_2S escaped into the laboratory.

The measuring devices, including the pressure gauge, rotameters, Pac III, manometer, as well as the pumps were all mounted on a sheet of plywood to ensure easy access to all measurements and equipment during each trial. The entire setup was placed under the fumehood in the laboratory and the fumehood fan was turned on prior to each testing event.

System verification

The system was initially tested for any leaks prior to the experiment. The system was placed under pressure and a mixture of soap and water were sprayed on all joints to observe any bubbling, which indicated leakage. After ensuring all the joints were well sealed, H_2S was injected into the system at a low rate to further ensure no leakage occured by using H_2S monitors placed near the system. The fan in the fumehood was also checked to verify that adequate pressure difference exists across the fan to draw air out from the fumehood. In addition, the Draeger Pac III monitor used to measure the exhaust gas from the system was calibrated.

Data Collection

Water

Prior to each trial the water flowrate was adjusted so when the water pump was turned on, the flowrate was known with no adjustments made to the system during the trials. The flowrate and the sprinkling time were used to calculate the water usage. Immediately before the H_2S gas was added to the tank in each study, the water would be turned on and allowed to reach the desired pressure, and was then left to run for 4 min, during which time the H_2S was injected into the tank.

H_2S gas

Calculations were made to determine the approximate length of time it would take for the PVC pipe to reach various concentrations over various H_2S injection rates. Based on these calculations, the size of the PVC pipe was selected and the inlet H_2S concentration was 1000 ppm, and initial studies were performed where the system were filled with H_2S to determine the length of time it takes to reach various concentrations (~200, ~400 ppm) inside the PVC pipe at various inlet flow rates. Adding the H_2S gas to the tank at 1.5 L/min for 2 min reached a level of 177 ppm inside the tank. This flowrate and time was used to add the H_2S to the system for subsequent experiments, and the optimum treatments were also tested at 5 L/min for 45 s, which reached 425 ppm. The inlet flow rates were also selected based on the concentration curves measured inside the PVC pipe to try to simulate the H_2S curves measured from agitated manure as in Chénard et al. (2003).

Exhaust air

The H_2S in the exhaust air was continuously monitored at 10 s intervals during each trial. The electrochemical sensor monitor (Draeger Pac III equipped with a Draeger H_2S sensor XS EC 1000 ppm (Draeger, Lübeck, Germany; reproducibility of 5%)) was downloaded regularly during each testing period. Immediately prior and upon completion of both the preliminary and final trials, the Pac III was calibrated using standard certified gases (0 and 98 ppm H_2S, (Praxair, Winnipeg Canada)), and each time the monitors showed little drift (<2 ppm), and resetting of the monitors was not required.

Temperature

The temperature were measured inside both the experimental and water tanks, and inside the laboratory. A datalogger was used to record these values during each trial, and the dataloggers were downloaded regularly.

Pressure difference

A manometer was connected to the PVC pipe with one end open to the room to monitor the pressure across the system.

Safety Protocols

When performing the trials all personnel had a personal Draeger microPac H_2S monitor (Draeger, Lübeck, Germany), and various microPac monitors were placed around the worksite to make sure the workers were at no time exposed to the H_2S gas. If the alarms on the monitors went off at 15 ppm, the workers were to immediately shut off the H_2S tanks and exit the laboratory until the alarm subsided. The exhaust fan in the fumehood was continuously running, so any H_2S gas would eventually be exhausted outside. Signs were posted on the laboratory door when the experiment was running to ensure those entering the lab are aware of the work being done in the lab and to advise people to evacuate the lab immediately if the alarm went off on the H_2S monitors.

Data Analysis

All the treatment combinations tested were compared to the control, where no liquid was added to the system. Both the maximum and the time weighted average (TWA) of the H_2S concentration was compared between the control and treatment. The TWA was taken over four minutes, with the average for each 60 s.

The following equation was used to determine the difference between the control and treatments:

$$\% \text{ Reduction in } H_2S = \frac{\text{Control} - \text{Treatment}}{\text{Control}} * 100$$

The optimum treatment combinations will be selected based on the preliminary results, and a controlled study will be completed using a randomized complete block design. In addition, once the optimum combinations of nozzle, operating pressure and treatment are found, further testing will be performed using the top three optimum combinations at different H_2S concentrations (100, 400 ppm).

Results

Temperature Effects

The effect of the sprinkled water temperature on the reduction of H_2S was studied. Figure 6 shows the results for the same operating conditions (normal tap water, full cone nozzle, 100 kPa (15 psi), with H_2S injected at 1.5 L/min for 2 min) with a 10°C difference in sprinkling water temperature. A 23% reduction in the maximum H_2S concentration was measured with the cooler water (15°C) versus the warmer water (25°C). These results were consistent with results obtained by Haimour and Sandall (1984), who also found that a reduction in water temperature increased the diffusivity of H_2S by pure water. It is expected that a further reduction in temperature would further reduce the H_2S concentration. For purposes of this study the testing was done using water at 17°C.

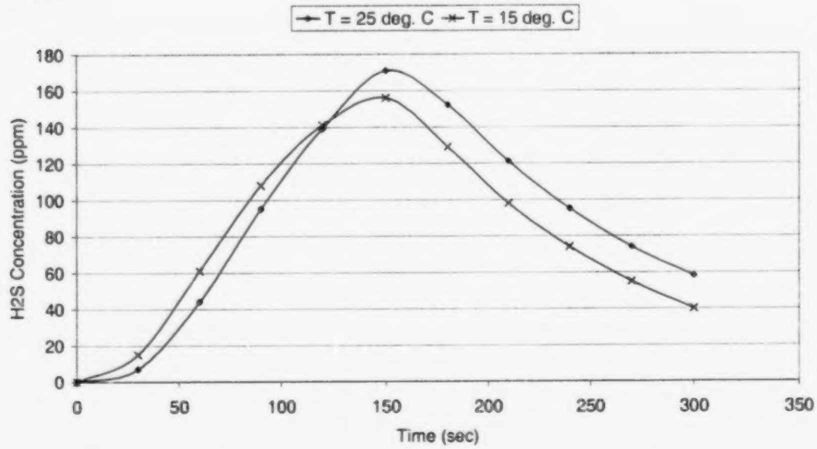


Figure 6. The effect of temperature on H_2S concentration. The full cone nozzle (D1.5-31) was used at 100 kPa.

Water Type

Testing with the addition of Ecosorb® essential oils in the water sprinkling supply resulted in a cross-sensitivity of the Pac III monitor with gases from the essential oils, which affected the resultant H_2S reading. As shown in Fig. 7, when diluted essential oil (400 mL Ecosorb® /6 L water) was sprinkled into the tank with no H_2S added, the H_2S concentration on the Pac III reached 29 ppm after two minutes. In addition, when undiluted Ecosorb® was sprinkled into the tank, the concentration reached almost 400 ppm, much higher than the H_2S concentration with no liquid sprinkling inside the system (186 ppm). In addition, the time for the Pac III to return to a concentration reading of 0 ppm after this test was much longer than a test where no Ecosorb® was exposed to the monitor. Attempts will be made to understand the impact of the essential oils on the sensitivity of the Pac III, but for purposes of this experiment, the essential oil was no longer investigated as a means to reduce the levels of H_2S.

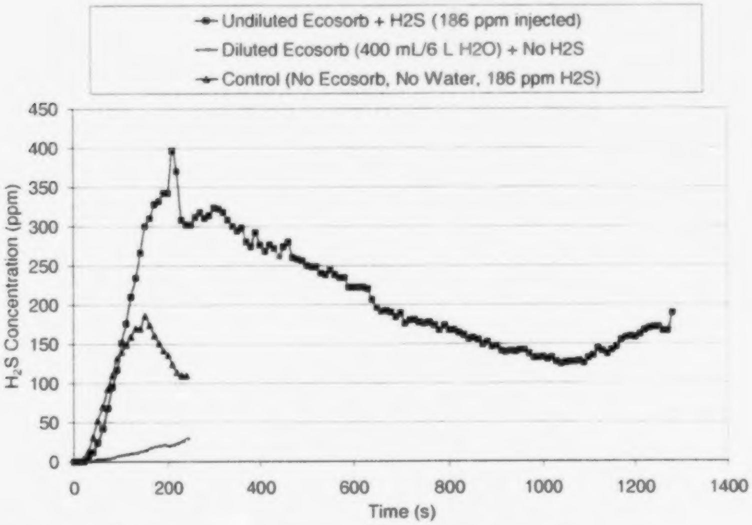


Figure 7. Results of using Ecosorb® in the H_2S system.

Studies with ferric sulfate revealed that the addition of the chemical to the incoming sprinkled water dropped the pH of the sprinkled water to ~2-3. As well, when the water with ferric sulfate was sprinkled, the H_2S concentration in the exhaust air reached 159 ppm, a 29% higher concentration than when the system was sprinkled with normal water (113 ppm) for the same nozzle and water pressure. Moreover, it was difficult to maintain the desired pressure of the system as the ferric sulfate did not dissolve well in the water and the ferric sulfate granules tended to block the nozzles. Based on these results, it was decided not to investigate the use of ferric sulfate further in this experiment.

Preliminary testing showed that increasing the pH of the sprinkled water to 9 has potential to reduce the concentration of H_2S in the exhaust more so than sprinkling normal tap water. Additionally, it has been found that a much smaller volume of water would be needed if the pH of the water were increased to 9, which will have the advantage of decreasing the volume of water to be used and stored in the manure pit. In addition, sprinkling water with hydrogen peroxide added reduced the H_2S to 70 ppm, a 61% reduction.

Nozzle Selection

After preliminary testing was done on the nozzles, it was apparent that when normal tap water was used, a nozzle with a higher flow rate would reduce the levels of H_2S gas more so than a nozzle with a lower flow rate. Figure 8 illustrates that the largest reduction in H_2S was seen with the full cone nozzle used at 240 kPa (0.6 L/min; 35% reduction), as compared to the hollow cone nozzle at both 100 kPa (0.3 L/min; 18% reduction) and 240 kPa (0.4 L/min; 19% reduction) and the full cone nozzle at 55 kPa (8 psi; 0.4 L/min; 32% reduction), all using normal tap water.

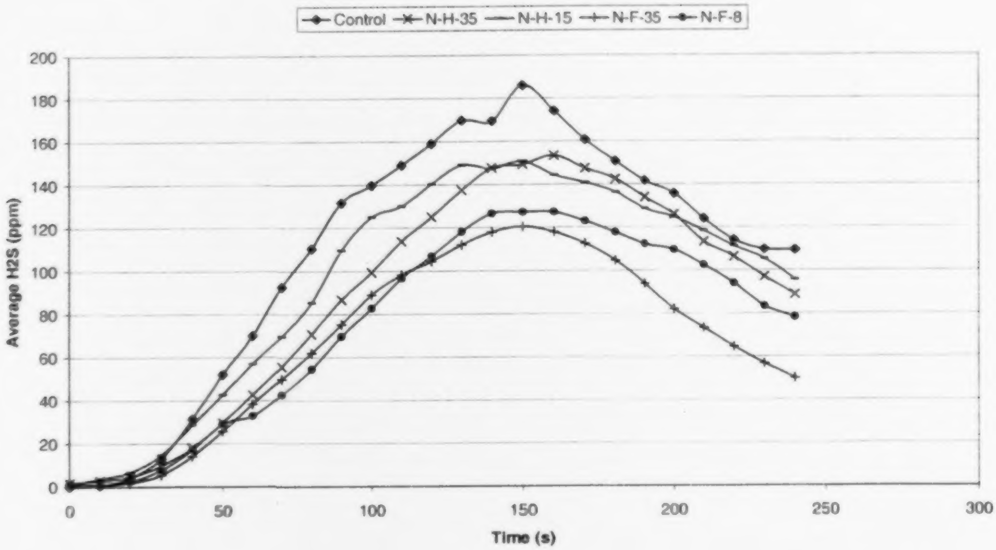


Figure 8. Summary of H_2S measurements with an H_2S injection of 1.5 L/min for 2 min. (Control, normal water with hollow cone (240; 100 kPa); full cone (240; 55 kPa)).

A third nozzle was selected after preliminary analysis showed that when both the hollow and full cone nozzles were sprinkled simultaneously at their maximum flowrates (1.0 L/min total), the H_2S concentration was reduced by 18% more than when the full cone nozzle was used at 240 kPa (0.6 L/min). In addition, when the full cone nozzle operated at 55 kPa and the hollow cone operated at 240 kPa, the same volume of water was being sprayed (3.4 L/min). For the same volume of water and the same operating conditions, the full cone nozzle was more efficient at reducing the levels of H_2S than the hollow cone nozzle. For this reason, the third nozzle was a full cone nozzle (D6.5, 0.094" TG Unijet Full Cone Nozzle; John Brooks Co.; Winnipeg, MB.), which had a higher capacity than the first full cone nozzle (1.78 – 5.68 L/min), so the effect of a higher flow rate on reduction of H_2S could be investigated. Table 1 is a summary of the nozzles used in this study, along with their operating pressures and flowrate per m^2 of surface area (L/min-m^2) that the water is sprinkled over.

Table 1. Summary of nozzles used for the current study.

Pressure		**Flowrate (L/m^2-min)****		
KPa	**psi**	**Nozzle 1**	**Nozzle 2**	**Nozzle 3**
35	5	-	-	25.2
70	10	2.7	5.4	28.2
100	15	2.8	5.6	30.6
140	20	2.8	5.7	33.0
170	25	2.9	5.9	35.4
200	30	3.0	6.1	40.2

*values in kPa were rounded up or down to their nearest factor of 5

**Nozzle 1 = hollow cone (0.19-0.42 L/min from 70-400 kPa)

Nozzle 2 = full cone (0.38-0.87 L/min from 70-400 kPa)

Nozzle 3 = full cone (1.78-5.68 L/min from 35-400 kPa)

Figure 9 is a summary of the results from using the three nozzles with different water treatments (normal tap water, water with hydrogen peroxide added, water with a pH 9, and no water added), sprinkled at different operating pressures. The results for water usage are presented in terms of flowrate per m^2 of surface area (L/min-m^2) that the water is sprinkled over, and the results for the H_2S reduction is presented as a percentage reduction. Each result was replicated three times. From Fig. 9, it is evident that the full cone nozzle with a higher flow rate, used with water at pH 9 and sprinkled at 170 kPa reduced the concentration of H_2S the greatest (79%), but the water usage (35.4 L/min-m^2) was much higher than the full cone nozzle with a lower flow rate, pH 9 at 100 kPa (5.8 L/min-m^2), which saw an H_2S reduction of 67%. Calculations show that if the hollow cone nozzle was used in a grower-finisher swine manure pit to sprinkle water over the entire pit for 15 min. while the pit was draining, the total volume of water used (1.0–1.6 m^3) would be in the range of 5–8% of the total manure pit volume. If the full cone nozzle with the higher capacity was used at 170 psi, the total volume of water used over 15 min. would be 11.1 m^3, or 57% of the total manure pit volume. Based on these results, it was concluded that the final trials would use only the initial hollow cone nozzle and full cone nozzle with a lower flow rate, and the nozzle with a higher flow rate would no longer be investigated as it utilized much more water than necessary (84%) for a 12% additional decrease in maximum H_2S concentration. This additional water would ultimately put a higher burden on the volume of water used, and would increase the volume of manure. This additional water would also increase both the volume needed to store the water in the lagoon, and the manure spreading costs. In addition, it is likely that spraying would not have to be performed over the entire manure pit, and total sprinkling time could be shorter than 15 min., so the addition of water using the hollow cone nozzle corresponding to 5-8% is likely a conservative estimate that could be reduced in the final design.

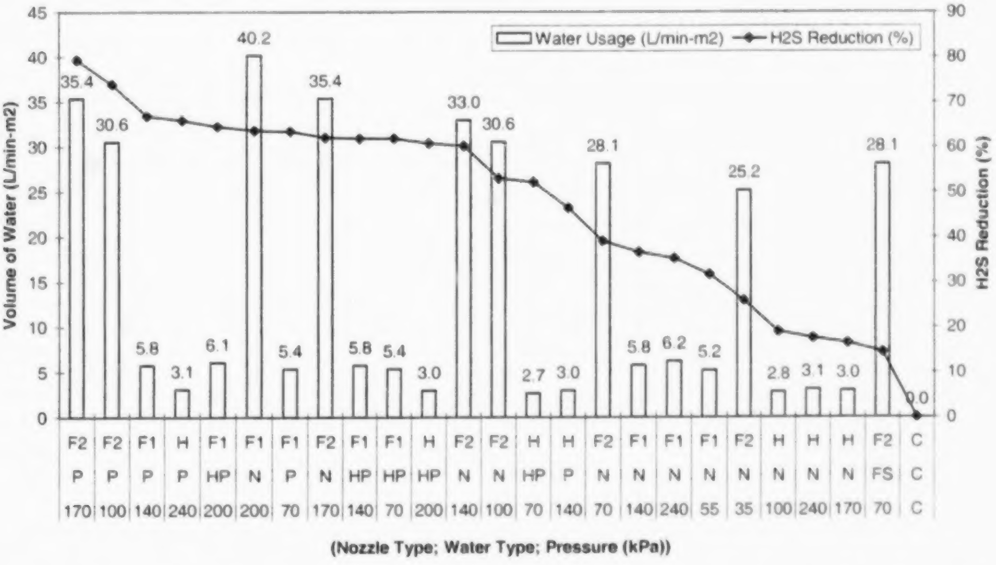


Figure 9. Summary of preliminary trials using three nozzle types (F1; F2 and H – full cone 1, full cone 2 and hollow cone, respectively) using different water treatments (P = pH 9; HP = hydrogen peroxide added to water; N = normal tap water; C = control (no water added) at various pressures.

Final Treatment

Based on preliminary results using the various treatments (three different nozzles, three operating pressures, and five water treatments), the final experiment used only the hollow and the initial full cone nozzles, with three operating pressures (70, 140, 200 kPa) and three water treatments (tap water, tap water with an increased pH 9 and tap water with hydrogen peroxide). Three repetitions were made for each treatment.

The results from this trial are presented in Fig. 10. There were no significant differences between the blocks ($p>0.05$), and there were significant differences among both water type and nozzle type ($p<0.05$). There was also a significant difference between the water*nozzle*pressure interaction ($p<0.05$), which tells us that each treatment was significantly different from the others. The best reduction of H_2S occurred when the hollow cone nozzle was used at 200 kPa using water at a pH of 9, resulting in a 79% reduction of the maximum H_2S. Use of a full cone nozzle at pressures 70, 140 and 200 kPa resulted in high levels of H_2S reduction as well, but the water volume used was much higher than for the hollow cone (18 – 63% more water).

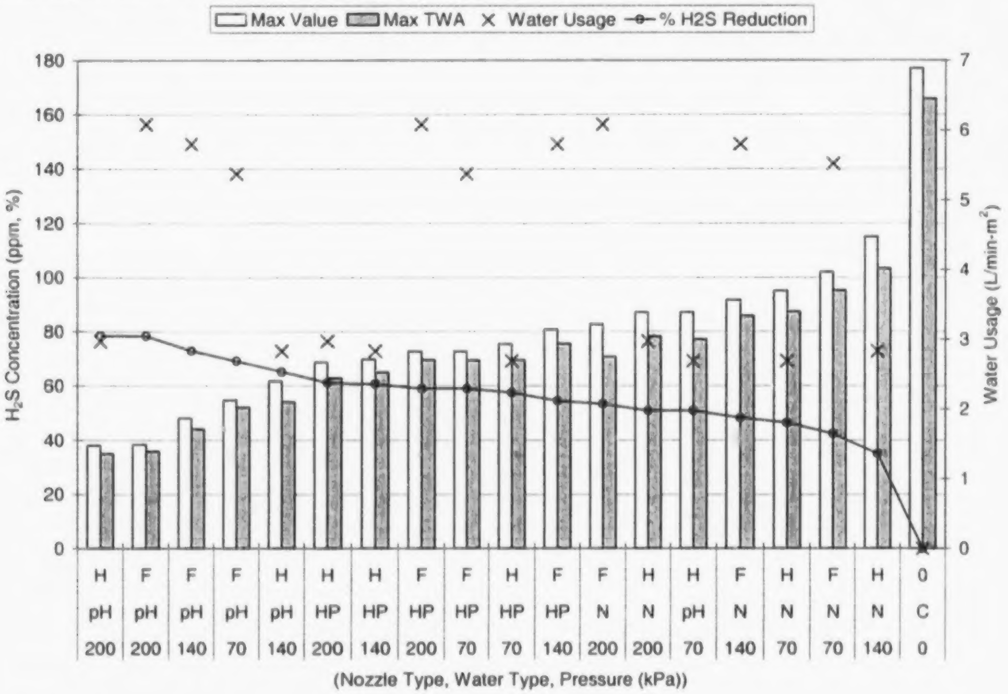


Figure 10. Summary of final trial results (Nozzle Types – H (hollow cone) and F (full cone); Water Type – pH (water at pH 9), HP (water with hydrogen peroxide added), and N (normal water); Pressures – 70, 140 and 200 kPa;).

Part 2 – Manure Study

Further studies were done using the top three optimum treatment combinations found in the laboratory study on reducing H_2S from agitated swine manure.

Objectives

Since the hollow cone nozzle saw a high reduction of H_2S (51 – 79% reduction) with tap water at pH 9 and used much less water than the full cone nozzle, the objective of the subsequent study was to investigate the use of hollow cone nozzles with tap water with pH 9 at 70, 140 and 200 kPa to reduce H_2S from agitated swine manure.

Methodology

Sixteen 170-L barrels were filled with manure from grower-finisher swine. A sewage pump was lowered into the manure pit in room 130W and manure was pumped into a large tub. The manure was further mixed in the tub using a power drill and paint mixer as in Fig. 11. After mixing, the manure was scooped into 170-L barrels, with one tub of manure filling four containers two-thirds full. A lid was placed on each barrel after filling with manure. Filling four barrels from one tub of manure allowed grouping of the manure samples, as each batch of manure varied slightly in consistency, and each tub of manure would be used for one treatment. Four barrels were used for the control and four barrels each for the three treatments. The barrels were transported to an empty room in the PSC barn and allowed to sit undisturbed for three days.

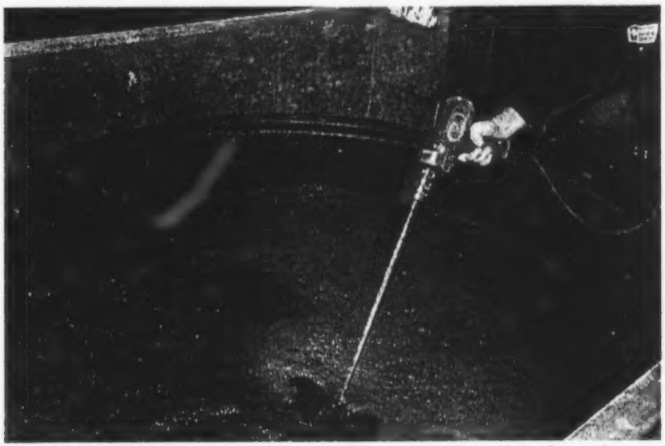


Figure 11. Mixing manure sample to be placed in barrels.

A single lid was designed and fabricated with a mixer, nozzles and exhaust and inlet ports as in Fig. 12. A bearing was welded onto the lid that held a paint mixer in place and allowed the mixer to be rotated using a power drill. Each hole made in the lid was sealed so no gases would escape through the system other than through the exhaust port. The same setup as the laboratory study was used to measure the H_2S in the exhaust air from the barrel (Fig. 5), with the exhaust air from the Pac III exhausted outside through the room fan.

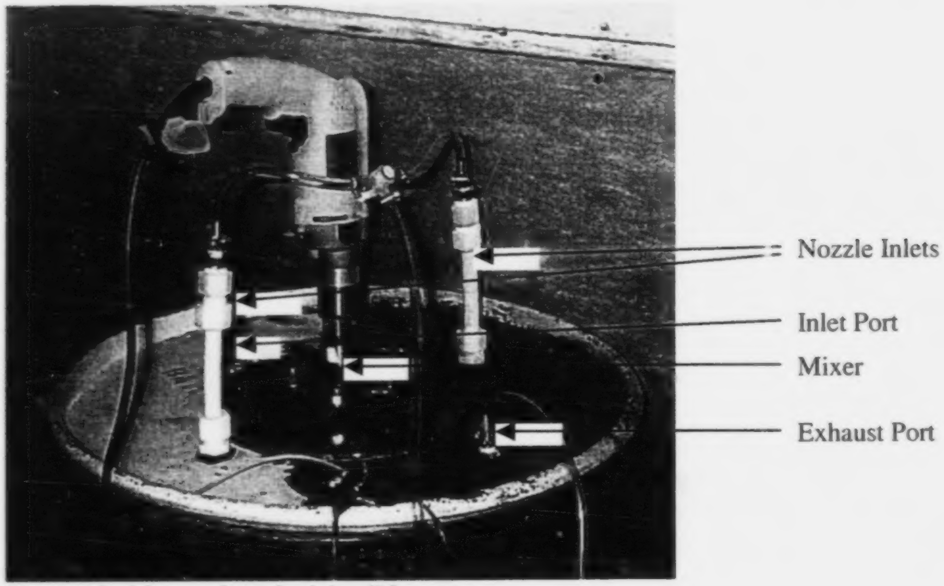


Figure 12. Manure barrel mixing lid.

For each measuring event, the lid on the manure barrel would be removed and the mixing lid was placed on the barrel. The mixer on the lid would agitate the manure slightly, and the exhaust pump was then turned on, drawing air from the barrel over the Draeger Pac III monitor. The mixer was allowed to remain stationary until the H_2S reading on the Pac III read <10 ppm, which generally took about 15 min. After the H_2S reading read <10 ppm on the Pac III, the power drill was turned on, and to ensure consistent mixing between barrels, a tachometer was used to measure the rotation speed of the mixer. Preliminary work was done to determine the optimum speed and time mixing to obtain a peak of H_2S from the barrel. For all treatments and controls, the manure was mixed at 220 RPM for 1.5 min. For the control barrels, no water was sprayed while mixing the manure, and the concentration of H_2S was measured in the exhaust. For the treatment barrels, the water was turned on prior to agitation.

Data Analysis

As with the laboratory phase of this study, the following equation was used to determine the difference between the control and treatments:

$$\%\text{ Reduction in } H_2S = \frac{\text{Control} - \text{Treatment}}{\text{Control}} * 100$$

Results

After placing the mixing lid on the barrel of manure and allowing the exhaust concentration of H_2S to reach <10 ppm, four control barrels were agitated and the H_2S concentration measured. An average of 148 ppm was found with the four control barrels, with a maximum of 520 ppm. However, when water at a pH of 9 was added to the system at 100 kPa using the hollow cone nozzle, and the manure was agitated in the same manner as the control, both the average and maximum H_2S concentration measured in the exhaust air of three treatments increased to 273 and 690 ppm, respectively. Figure 13 depicts the results read by the Draeger Pac III monitor for this study. These results were the reverse of what was expected based on the laboratory study, where sprinkling the water reduced the levels of H_2S. Since the laboratory study used pure H_2S gas and the manure study contains numerous other gases in the exhaust air, it is suspected that the other gases have an impact on both the Draeger Pac III monitor and the actual levels of H_2S inside the headspace of the barrel.

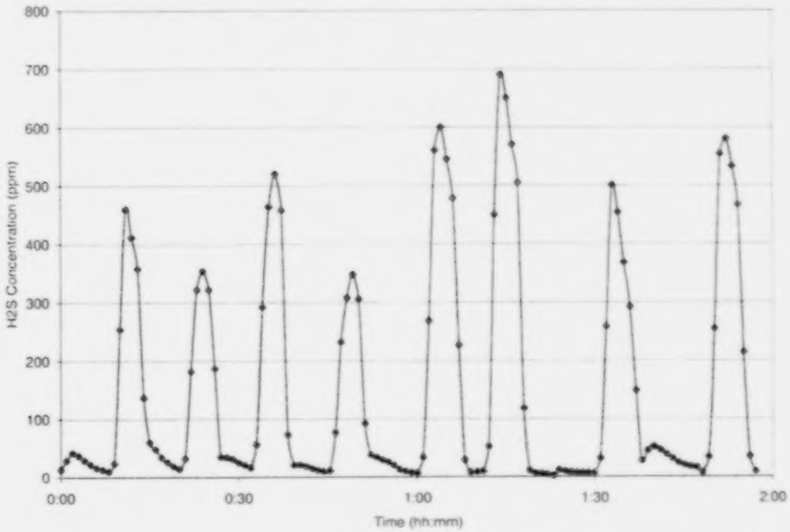


Figure 13. Summary of control and treatment with manure barrels. The first four peaks are the control tests, with no water added. The last four peaks are the treatment, with water with pH 9 sprinkled using a hollow cone nozzle at 100 kPa.

A test was done to determine what occurs inside the manure barrel when water was sprinkled and no agitation occurred. The mixing lid was placed inside one barrel and the concentration of the exhaust air was allowed to reach 24 ppm. When the water at pH 9 was sprinkled inside the barrel for 30 min at 100 kPa, with no manure agitation, sporadic levels of H_2S were recorded over the 30 min, with a maximum of 1000 ppm and an average of 343 ppm, as shown in Fig. 13. It is uncertain why the H_2S levels fluctuated as in Fig. 14 and further research needs to be done to explain the response of the Draeger Pac III monitor to the gases from the manure barrels.

In the Draeger Pac III operating manual there is a list of cross-sensitivities of other gases with the Pac III, including ammonia, carbon dioxide, methane, and several other gases. This list is presented in Table 2, and the largest cross sensitivity of a single gas on the Pac III that is listed in the manual is from methanol, which could see a deviation of $\leq$20 ppm. However, the remainder of the gases should have an impact on the deviation from $\leq$1 to $\leq$10 ppm. As mentioned in the manual, there could also be other gases that affect the reading of the Draeger Pac III that are not listed in the operating manual. When the water is sprinkled inside the manure barrel, it may be possible that the sprinkled water affects other gases emitted from the manure and subsequently affect the reading of the Pac III, however, the combined cross sensitivities of the gases listed in the manual reach ~110 ppm, and the levels recorded by the Pac III reached 1000 ppm with no manure agitation when the water was sprinkled. Further work needs to be done to establish the effect of the other manure gases on the reading of the Draeger Pac III monitors.

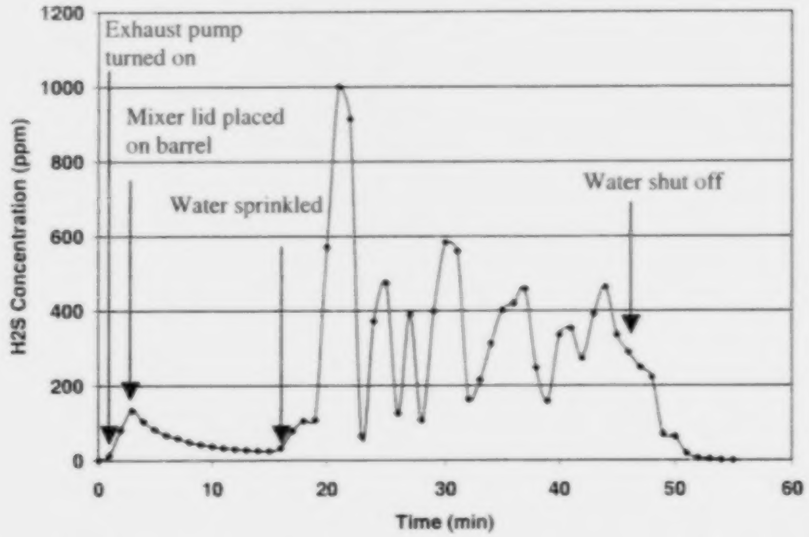


Figure 14. Effect of sprinkling water on manure in barrel with no agitation of the manure. At time 0 the exhaust pump was turned on. After 2 min. the mixer lid was placed on the manure barrel and left to sit for 13 min., and the exhaust concentration measured 24 ppm. The sprinkling water was turned on at minute 13 and left on to minute 45, with no manure agitation. After turning the water off, the H_2S concentration reached 0 ppm in 6 min, at 52 min. The maximum H_2S concentration read by the Draeger Pac III monitor is 1000 ppm.

Basic additional testing was done to compare the Draeger Pac III monitor, H_2S chemical detector tubes and gas chromatography. The manure was mixed and the exhaust air was drawn over the Pac III and into a Teflon bag. The air in the bag was then drawn through a chemical detector tube (Matheson pump) and the bag was then sent to EnviroTest Laboratories for gas chromatography (GC) analysis on the H_2S. Two air samples were collected from agitated manure with no water sprinkled, and two air samples were collected from agitated manure with water sprinkled at a pH 9 at 140 kPa. The results are summarized in Table 3, including both the maximum and average H_2S concentration from the Draeger Pac III monitor. The data were similar between the chemical tubes and the GC, but the Draeger Pac III reading was much higher than the chemical tube and GC measurements. The control tests saw an average of 197 ppm and a maximum of 516 ppm with the Pac III, whereas the chemical detector tube saw an average of 45 ppm, and the GC saw 23 ppm with the second sample as the first sample bag was empty when received by the laboratory. The treatment tests saw a combined average of 508 ppm and a maximum of 980 ppm using the Pac III, whereas the chemical detector tube saw an average of 98 ppm, and the GC saw an average of 104 ppm. Based on all three methods of measurements, it appears that sprinkling water actually increases the concentration of H_2S inside the headspace of the 170-L barrel with manure, which is the opposite of what was seen in the laboratory study. It must be emphasized that these manure study results are only preliminary and further work needs to be done to verify and explain the results, which was outside the scope of the current project.

Table 2. Summary of cross-sensitivities listed in the Draeger Pac III operating manual.

Gas / Dampf Gas / Vapour	Chemisches Symbol Chemical symbol	Testgas-konzentration Test gas concentration	Abweichung des Meßwertes in ppm H_2S Deviation from measured value in ppm H_2S
Aceton / Acetone	CH_3COCH_3	1 000 ppm	≤ 4
Ammoniak / Ammonia	NH_3	500 ppm	≤ 1
Benzol / Benzene	C_6H_6	0,6 Vol.-%	≤ 1
Carbonylchlorid / Carbonylchloride	$COCl_2$	50 ppm	≤ 1
Chlor / Chlorine	Cl_2	8 ppm	≤ 2 (–)*
Chlorwasserstoff / Hydrogen chloride	HCl	40 ppm	≤ 1
Cyanwasserstoff / Hydrogen cyanide	HCN	50 ppm	≤ 1
Ethanol / Ethanol	C_2H_5OH	200 ppm	≤ 2
Ethanthiol / Ethyl mercaptan	C_2H_5SH	10 ppm	≤ 5
Ethen / Ethene	C_2H_4	1 000 ppm	≤ 10
Ethin / Ethine	C_2H_2	0,6 Vol.-%	≤ 10
FAM-Normalbenzin / FAM petrol (DIN 51635, DIN 51557)	——	0,55 Vol.-%	≤ 1
Hexan / Hexane	C_6H_{14}	0,6 Vol.-%	≤ 1
Kohlendioxid / Carbon dioxide	CO_2	1,5 Vol.-%	≤ 1 (–)*
Kohlendisulfid / Carbon disulphide	CS_2	15 ppm	≤ 1
Kohlenmonoxid / Carbon monoxide	CO	125 ppm	≤ 3
Methan / Methane	CH_4	5 Vol.-%	≤ 1
Methanol / Methanol	CH_3OH	200 ppm	≤ 10
Oktan / Octane	C_8H_{18}	0,4 Vol.-%	≤ 1
Propan / Propane	C_3H_8	1 Vol.-%	≤ 1
Propen / Propene	C_3H_6	0,5 Vol.-%	≤ 1
Phosphorwasserstoff / Phosphine	PH_3	5 ppm	≤ 5
Schwefeldioxid / Sulphur dioxide	SO_2	20 ppm	≤ 4
Stickstoffdioxid / Nitrogen dioxide	NO_2	20 ppm	≤ 1
Stickstoffmonoxid / Nitrogen monoxide	NO	20 ppm	≤ 10
Tetrahydrothiophen / Tetrahydrothiophene	C_4H_8S	10 ppm	≤ 4
Tuol / Toluene	$C_6H_5CH_3$	0,6 Vol.-%	≤ 1
Wasserstoff / Hydrogen	H_2	1 Vol.-%	≤ 10
Xylol / Xylene	$C_6H_4(CH_3)_2$	0,5 Vol.-%	≤ 4

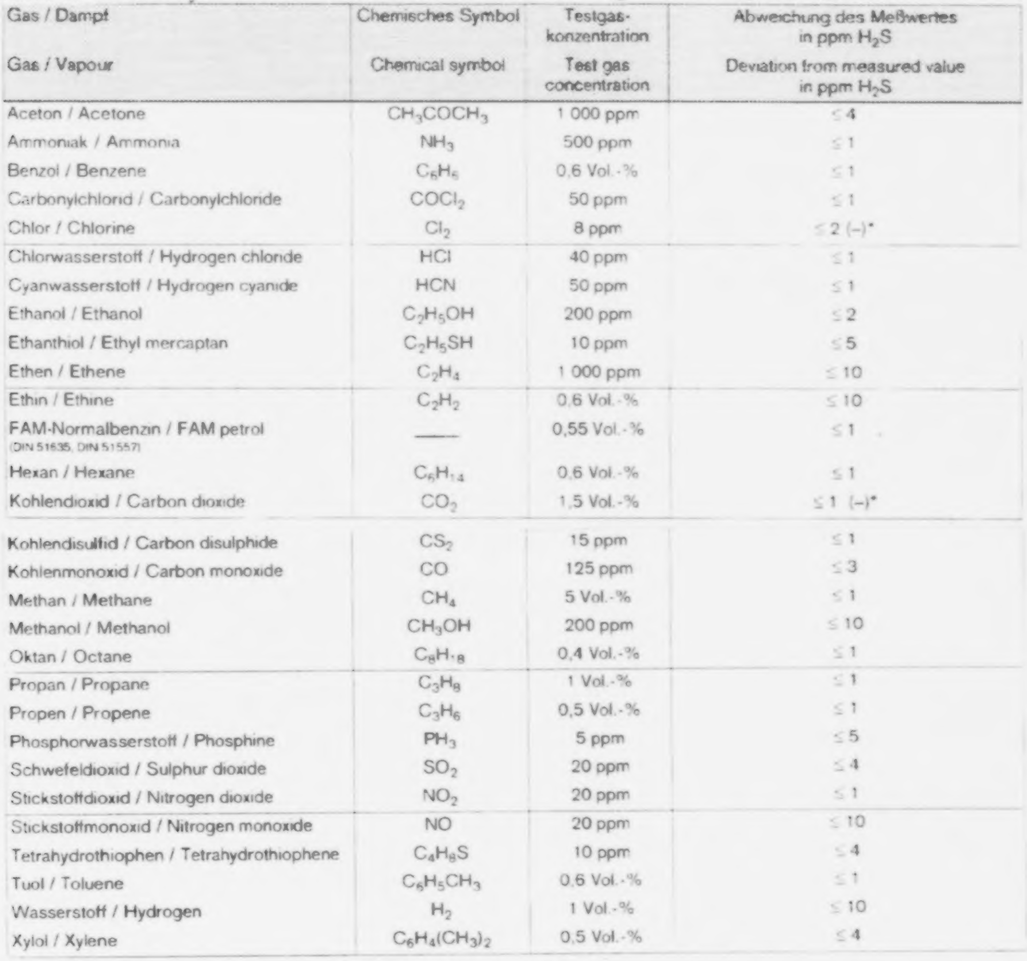
Table 3. Preliminary comparison of Draeger Pac III monitor (average and maximum values), chemical detector tubes and gas chromatography for control and treatment (water sprinkled at a pH 9, 140 kPa).

Sample	Type	Draeger Pac III (ppm) Average (ppm)	Draeger Pac III (ppm) Maximum (ppm)	Chemical Tube (ppm)	Gas Chromatography (ppm)
1	Control	245	765	45	-*
2	Control	149	268	45	23
3	Treatment	547	975	110	110
4	Treatment	470	985	85	97

*bag was empty when it was received by the laboratory

Contact was made with various individuals to try to explain the results seen from this study. Representatives from Draeger were contacted, and they suspected that the presence of other gases from the manure might have affected the readings of the electrochemical sensor in the Draeger Pac III monitor. In order to test this theory, a sample of air from the agitated manure would ideally need to be analyzed using gas chromatography in order to identify the compounds that

Table 2. Summary of cross-sensitivities listed in the Draeger Pac III operating manual.



Gas / Dampf Gas / Vapour	Chemisches Symbol Chemical symbol	Testgas-konzentration Test gas concentration	Abweichung des Meßwertes in ppm H_2S Deviation from measured value in ppm H_2S
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Chlor / Chlorine	Cl_2	8 ppm	≤ 2 (–)*
Chlorwasserstoff / Hydrogen chloride	HCl	40 ppm	≤ 1
Cyanwasserstoff / Hydrogen cyanide	HCN	50 ppm	≤ 1
Ethanol / Ethanol	C_2H_5OH	200 ppm	≤ 2
Ethanthiol / Ethyl mercaptan	C_2H_5SH	10 ppm	≤ 5
Ethen / Ethene	C_2H_4	1 000 ppm	≤ 10
Ethin / Ethine	C_2H_2	0,6 Vol.-%	≤ 10
FAM-Normalbenzin / FAM petrol (DIN 51635, DIN 51557)	——	0,55 Vol.-%	≤ 1
Hexan / Hexane	C_6H_{14}	0,6 Vol.-%	≤ 1
Kohlendioxid / Carbon dioxide	CO_2	1,5 Vol.-%	≤ 1 (–)*
Kohlendisulfid / Carbon disulphide	CS_2	15 ppm	≤ 1
Kohlenmonoxid / Carbon monoxide	CO	125 ppm	≤ 3
Methan / Methane	CH_4	5 Vol.-%	≤ 1
Methanol / Methanol	CH_3OH	200 ppm	≤ 10
Oktan / Octane	C_8H_{18}	0,4 Vol.-%	≤ 1
Propan / Propane	C_3H_8	1 Vol.-%	≤ 1
Propen / Propene	C_3H_6	0,5 Vol.-%	≤ 1
Phosphorwasserstoff / Phosphine	PH_3	5 ppm	≤ 5
Schwefeldioxid / Sulphur dioxide	SO_2	20 ppm	≤ 4
Stickstoffdioxid / Nitrogen dioxide	NO_2	20 ppm	≤ 1
Stickstoffmonoxid / Nitrogen monoxide	NO	20 ppm	≤ 10
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4	Treatment	470	985	85	97

*bag was empty when it was received by the laboratory

Contact was made with various individuals to try to explain the results seen from this study. Representatives from Draeger were contacted, and they suspected that the presence of other gases from the manure might have affected the readings of the electrochemical sensor in the Draeger Pac III monitor. In order to test this theory, a sample of air from the agitated manure would ideally need to be analyzed using gas chromatography in order to identify the compounds that may be present in the air. This test would be an additional cost to the project that was not covered in the original budget, and was not able to be completed at the present time. Representatives from Draeger also mentioned that the presence of aerosols can be a problem for electrochemical sensors, but the spray from the nozzles had large enough droplets that it would not be considered an aerosol, and additionally, the same spray in the laboratory setting did not appear to have an adverse affect on the readings of H_2S by the Pac III.

A Chemical Engineering professor from the College of Engineering at the University of Saskatchewan was also contacted for this study. He suggested that we use an alternative form of measurement such as gas chromatography for this study. However. this was a great cost at about $165 a sample, which was not covered in the original budget.

A second company (Levitt Safety) which manufactures electrochemical sensors was invited to come to the barn and try their H_2S monitor (Scott Scout) in conjunction with the Draeger Pac III. The manure was agitated until a reading of about 150 ppm was shown on the Scott Scout monitor, and then the agitation stopped. The water was then turned on, and the reading on the monitor reached 1000 ppm shortly, which was the same result as with the Draeger Pac III monitor. This told us that there was something happening with the manure gases and the electrochemical sensor setup, and requires additional consideration.

Based on the results from this study, it is apparent that it is very important to verify that the Draeger Pac III is giving reliable readings of the H_2S from swine manure. These monitors are currently in use by the swine industry, and we need to ensure that they give us the proper values of H_2S gas that is present in the air. The next step that is strongly recommended is to systematically verify the Draeger Pac III monitors by measuring the exhaust gases from manure using a variety of methods, including gas chromatography, chemical detector tubes, Draeger Pac III monitors, and other monitors currently used to measure H_2S.

■ Module 3 – Development and Testing of a Manure Scraper to Reduce Concentrations of Hydrogen Sulphide Gas in a Grower-Finisher Swine Room

Background

Levels of hydrogen sulphide have been found to reach dangerous levels in swine barns, especially when manure is agitated (Chénard et al., 2003). Exposure to H_2S can have detrimental effects on both workers and swine and can be potentially dangerous at excessively high levels (CHEMINFO, 2000). Economical and practical preventative measures need to be implemented to ensure that the H_2S levels do not reach hazardous proportions in swine barns to protect the health and safety of both workers and swine. Modification of the current design of shallow pit in-barn manure handling system to allow for more frequent and complete removal of manure from the production rooms has the potential to reduce H_2S production and emission.

Objectives

The objective of this study was to develop and evaluate a liquid manure handling system to reduce the exposure of swine barn workers and animals to hydrogen sulphide gas during in-barn manure handling activities.

Methodology

Experimental approach

Two commercial grower-finisher rooms with partially slatted floors at PSCI were used over four production cycles. Each room contained 6 pens, and for this experiment one pen remained empty throughout the trial and the other pens had 14 pigs each, for a total of 70 pigs per room. The rooms were mirror images of each other, and both used dry feeders with an automatic feeding system and nipple drinkers. In one of the rooms (Experimental), a manure scraper system was installed and operated daily to remove the manure from the room; the other room (Control) was operated normally, i.e., manure was allowed to accumulate in the pits, and was drained on a predetermined schedule by pulling the pit plugs. Pigs entered the rooms at about 21.5 kg and remained in the rooms for 12 weeks. The pigs were weighed at the beginning of each trial and sorted to ensure that the difference in the total starting weight for the two rooms was within ± 1.0 kg. Pigs were fed ad libitum with commercial mash diets for grower-finisher pigs.

Scraper set-up

A manure scraper system was assembled and installed in one grower-finisher room with a 0.6-m deep manure channel and a pit plug at both ends. The system was made from components of a commercially-available scraper system used in some swine operations in Québec and in other livestock (dairy) industries (Figs. 15 & 16). A false flooring was built inside the manure pit to raise the manure pit floor by 0.25 m at one end, sloping down to a height of 0.2 m at the other end of the manure pit (Fig. 17). One end of the false floor was 1.1 m from the drain at the high end of the slope, and at the low end of the false floor, the false floor end was 1.6 m from the other drain. The false floor was needed to create an area at the end of the floor for the manure to accumulate, which helped to ensure complete drainage of the manure. Two manure tubs (Fig. 18) were built out of mild steel and one was placed at each end of the false floor. Both tubs were provided with sloping walls to ensure complete drainage of the manure into each pit opening and to prevent retention of any manure from which H_2S could be produced.

A removable retaining wall was installed at the low end of the false floor (Fig. 17). This design allowed for two possible manure removal methods: 1) scraping to the top of the slope with the wall trapping both the liquids and solids above the false floor and the scraper blade removing the manure solids while retaining the liquids; and 2) scraping to the bottom of the slope with the wall removed and the manure mixture removed daily from the pit. After the daily operation of the scraper, the plug at the bottom of the filled accumulation pit was pulled to let the manure drain as a slurry mixture. The false floor and tubs were sealed around all edges to prevent any manure infiltration.

After each monitored week, the temporary wall in the pit was either added or removed to reverse the scraping direction for the subsequent monitoring week, thus, data was collected from alternating scraping direction during each trial.

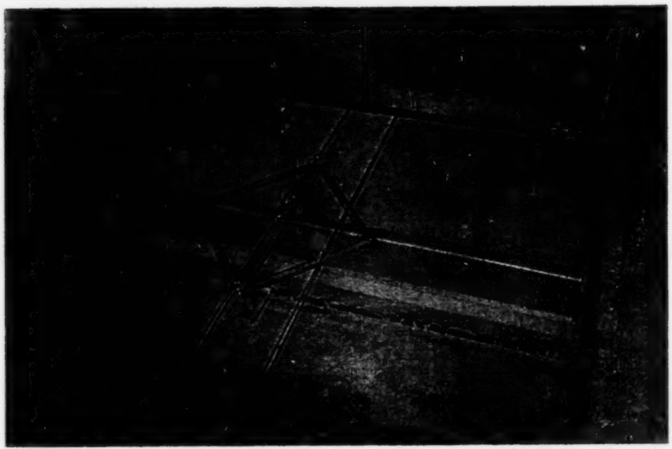

Figure 15. Scraper blade that was pulled over the false flooring. The manure pit has drains at both ends, through which the scraped manure was drained to the sewer line.

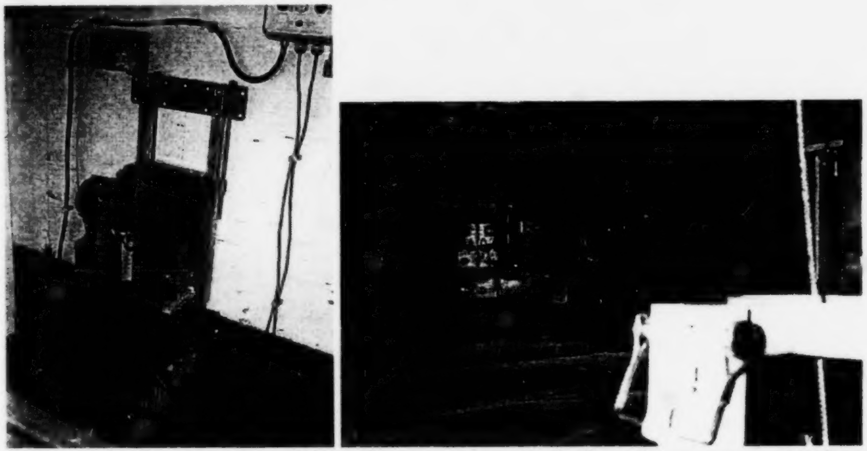

Figure 16. Components of the scraper system including the motor, controls, and pulley system used to pull the scraper blade in both directions.

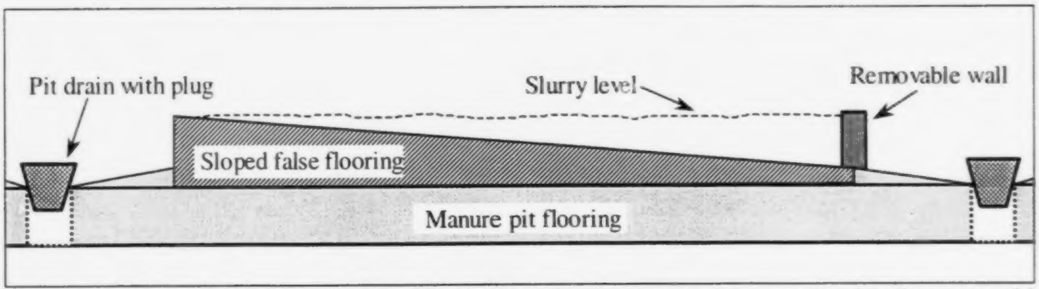

Figure 17. Schematic diagram of the sloped false flooring in the manure pit with the removable retaining wall in place (not drawn to scale).

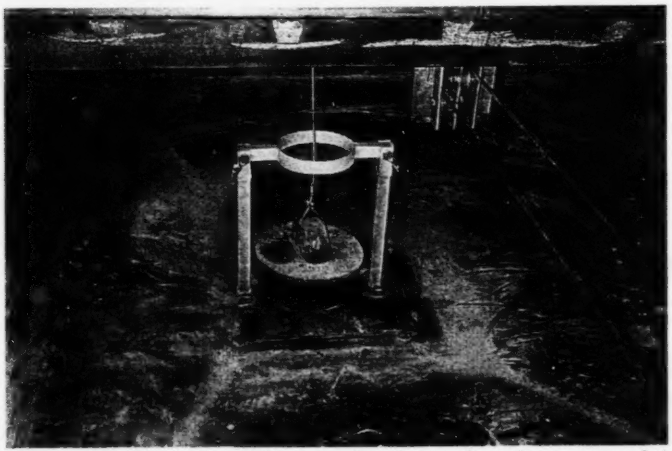

Figure 18. Pit drain with a pit plug located at the center of the accumulation tub. At each end of the pit, the sloping tub was installed to facilitate clearing the manure as the scraper was operated.

Data Collection

The room air quality and H_2S concentrations in the experimental (scraper) room were compared to an identical room with conventional plugs (control) over four production cycles. Four one-week periods were monitored over each production cycle: weeks 4, 6, 8 and 10. The pit plug in the control room was pulled in the middle of each of the one-week periods. The schedule of monitoring was set to coincide with normal plug pulling schedules in the production room, which allowed for manure to accumulate initially over a 4-week period while the pigs were small, while subsequent tests were done after every two weeks to account for larger manure production as the pigs grew larger. For each scraping and pulling event during the monitored week, two H_2S monitors (Model Pac III, with XS EC 1000 ppm H_2S sensor, Draeger, Lübeck, Germany; reproducibility of 5%) were installed in each room: one over the middle of the pit (middle pen) and another directly above the plug about 1 m off the floor. The monitors were turned on five minutes before pulling the plug. Preliminary tests were done to determine the length of time the pit drains need to remain open for the slurry to drain completely, since leaving the drain open longer than necessary could allow a back draft of H_2S to the room from the sewer line. After the plug was replaced, the monitor remained on for another 5 min to obtain H_2S measurements both before and after the pulling event.

In the experimental room, the scraper system was used daily and the pit plug was remotely pulled daily as well. The monitors were turned on five minutes before scraping the channel. After scraping was completed, the plug was pulled and the plugs remained open for 10 min. After replacing the plug, the monitor remained on for another 5 min to obtain H_2S measurements both before and after the pulling event. The air quality in both rooms was measured on a continuous basis during the monitored week. Ammonia concentrations were measured at the inlet and outlet of both rooms using a sampling manifold system attached to an ammonia analyser (Model Chillgard RT, MSA Canada, Edmonton, AB; accuracy of ±2 ppm). Temperature and relative humidity were measured every minute and averaged every 15 minutes; the fan speed and static pressure in the room were also monitored to calculate the ventilation rate.

Data analysis

The H_2S levels were compared between the two rooms in terms of the maximum daily H_2S concentration and the 15-min time-weighted average (TWA) to determine the percent reduction in H_2S. The ammonia emission levels were compared between the two rooms as well using the following equation:

$$\%\ \text{Reduction} = \frac{\text{Control} - \text{Experimental}}{\text{Control}} \times 100 \qquad (1)$$

The time-weighted average values were calculated by:

$$\text{Time-weighted average, TWA} = \frac{\Sigma(H_2S\ \text{concentration readings x Sampling interval})}{\text{Sampling duration}} \qquad (2)$$

The ammonia emission for each room was calculated using the following equation, with the appropriate conversion of units:

$$\text{Emission rate} = \frac{(\text{Exhaust conc. - Inlet conc.})}{10^6} \text{ x } 0.6894 \text{ x Vent. rate x } 3600 \qquad (3)$$

where:
Emission rate = ammonia emitted from the room, g hr^{-1}
Exhaust conc. = ammonia concentration at exhaust, ppm
Inlet conc. = ammonia concentration at inlet, ppm
Vent. rate = room ventilation rate, L s^{-1}

and the density of ammonia gas was assumed constant at 0.6894 kg m^{-3}, equivalent to ammonia gas density at standard pressure and at temperature of 25 °C.

Results

Summary of trials

Four trials were completed from March 8, 2004 to April 8, 2005, corresponding to four production cycles. Table 4 summarizes the average values for temperature, relative humidity (RH), and ventilation rates in the two rooms during the weeks that were monitored. Ambient conditions during Trial 2 were warm, thus the ventilation rates in both rooms were higher compared to the rest of the trials. Additional sampling week was done for both Trials 3 and 4 to increase the total size of the data set. In general, nearly similar conditions were maintained in both rooms throughout the trials, as can be observed from the close mean values for temperature, RH and ventilation rates measured in the two rooms. Paired t-test comparison between the average weekly values in the two rooms showed no significant difference ($P>0.05$) between these measured parameters.

Table 4. Summary of weekly average values for temperature, relative humidity and ventilation rates measured in the control and scraper rooms.

Trial No.	Date	Average room temperature (°C)		Average relative humidity (%)		Average ventilation rate (L/s)	
		Control	Scraper	Control	Scraper	Control	Scraper
Trial 1	8-12Mar04	18.3	18.3	n/a	48.5	808	768
	22-26Mar04	16.3	16.4	51.5	52.2	859	881
	5-9Apr04	16.2	15.5	43.8	43.5	2111	1661
	19-23Apr04	16.4	16.1	36.6	37.9	2382	2310
Trial 2	28Jun-2Jul04	23.9	23.1	49.5	47.2	2938	3035
	19-23Jul04	23.4	22.8	63.0	63.1	3208	3230
	9-13Aug04	21.8	19.6	59.0	58.9	2858	3022
	23-27Aug04	17.3	17.7	63.4	62.1	2689	3039
Trial 3	11-15Oct04	17.4	17.9	48.0	46.0	1309	1118
	25-29Oct04	15.7	16.1	56.9	54.3	823	827
	8-12Nov04	14.6	15.1	53.9	49.3	871	766
	23-26Nov04	14.4	14.6	57.5	54.8	735	721
	12-14Dec04*	14.5	15.0	57.4	56.0	808	866
Trial 4	7-11Feb05	16.8	18.1	49.8	49.3	381	371
	21-25Feb05	16.7	17.1	50.0	52.3	413	391
	7-11Mar05	16.3	16.1	52.5	51.7	753	678
	21-24Mar05	14.8	14.8	53.2	53.7	647	721
	4-7Apr05*	16.2	16.1	52.2	51.4	1953	2234
	Average	17.3	17.2	52.8	51.8	1474.7	1479.9
Std. Deviation (SD)		2.9	2.5	6.7	6.2	974.7	1031.8

*Additional sampling week was done for Trials 3 and 4.
n/a – data not available, instrument malfunction

Hydrogen sulfide concentrations

During each monitored week, the H_2S concentrations were measured in each room during the 15-min period that the scraper system was operated in the scraper room. However, initial results showed that no (zero) detectable H_2S was measured in the control room during days in which the pit plug in the room was not pulled, and measurable H_2S readings were detected only during the day that the pit plug was actually pulled. Thus, in subsequent weeks, the H_2S levels were monitored in the control room only during the day that the pit plug was pulled in that room. Table 5 summarizes the maximum H_2S concentrations measured in the two rooms during the day that the pit plug was pulled in the control room.

The H_2S monitors were placed at two locations: over the pit plug area, and at the middle of the pit (middle pen), both at about 1 m height. In the control room, the average peak H_2S levels measured over the plug area and at the middle pen were 23.5 ppm (SD = 25.7 ppm) and 4.8 ppm (SD = 7.4 ppm), respectively. In the scraper room, the corresponding values were 2.2 ppm (SD = 5.1 ppm) and 0.7 ppm (SD = 1.8 ppm), respectively. Within each room, comparison of maximum H_2S readings at the two locations showed significant difference ($P<0.05$) between the values in the control room, but not significantly different ($P > 0.05$) in the scraper room. Between the two rooms, the maximum H_2S values measured at the two locations were significantly different ($P < 0.05$). Additionally, using Equation 1, the average peak H_2S concentrations in the scraper room were lower by 91% over the plug and by 85% over the middle pen compared to the same locations in the control room.

From a health and safety point of view, the maximum H_2S levels in the control room exceeded the 15-min average contamination limit value of 15 ppm H_2S (Saskatchewan Occupational Health and Safety Regulations, 1996) on nine occasions during the four trials. In the scraper room, the limit value was exceeded once (Trial 4, week 1), but it was documented that there was a backflow of gases from the sewer lines due to manure pit plug-pulling taking place in an adjacent room at about the same time when this measurement was taken.

Table 5. Summary of maximum H_2S concentration (ppm) measured in the control and scraper rooms.

		Control		Scraper	
Trial No.	Date	Over plug	Middle pen	Over plug	Middle pen
Trial 1	10-Mar-04	4.0	2.0	0.0	0.0
	24-Mar-04	0.0 **	0.0	0.0	0.0
	07-Apr-04	9.0	0.0	11.0	7.0
	21-Apr-04	12.0	4.0	0.0	0.0
Trial 2	30-Jun-04	12.0	2.0	0.0	0.0
	21-Jul-04	95.0	n/a	6.0	n/a
	11-Aug-04	40.0	30.0	2.0	0.0
	25-Aug-04	30.0	10.0	1.0	2.0
Trial 3	13-Oct-04	0.0	0.0	0.0	0.0
	27-Oct-04	48.0	4.0	0.0	0.0
	10-Nov-04	55.0	0.0	0.0	0.0
	24-Nov-04	18.0	11.0	0.0	0.0
	15-Dec-04*	18.0	7.0	0.0	0.0
Trial 4	09-Feb-05	7.0	3.0	19.0	0.0
	23-Feb-05	0.0	0.0	0.0	0.0
	09-Mar-05	0.0	0.0	0.0	0.0
	23-Mar-05	52.0	4.0	0.0	0.0
	06-Apr-05*	23.0	5.0	0.0	3.0
	Average	23.5	4.8	2.2	0.7
	SD	25.7	7.4	5.1	1.8

*Additional sampling week was done for Trials 3 and 4.

**Below instrument detection limit (0.1 ppm).

n/a – data not available, instrument malfunction

Similarly, the 15-min TWA values were calculated using Equation 2 for both rooms on the same monitored days and summarized in Table 6. In the control room, the average value over the plug area (4.1 ppm, SD = 5.2 ppm) was higher than over the middle pen (1.1 ppm, SD = 1.5 ppm). Similar trend was observed in the scraper room. Comparison of the values between the two rooms showed that the scraper room had 15-min TWA values lower by an average of 96% over the plug area and by an average of 95% over the middle pen. Furthermore, the 15-min TWA values for the scraper room were generally less than 2 ppm and did not exceed the contamination limit value of 15 ppm H_2S during the four trials. The corresponding values in the control room had one measurement (19.4 ppm; Trial 2, week 2) that exceeded the limit value. Although on three occasions the H_2S readings in the scraper room were actually higher than that in the control room, these comparisons suggest general effectiveness of the scraper system in reducing H_2S concentrations, and consequently reducing the risk of exposure of workers to H_2S associated with clearing manure from the pits.

Table 6. Summary of 15-min TWA values for H_2S (ppm) measured from the control and scraper rooms.

		Control		Scraper	
Trial No.	Date	Over plug	Middle pen	Over plug	Middle pen
Trial 1	10-Mar-04	1.1	0.2	0.0	0.0
	24-Mar-04	0.0	0.0	0.0	0.0
	07-Apr-04	0.0	0.0	0.9	0.6
	21-Apr-04	1.6	1.0	0.0	0.0
Trial 2	30-Jun-04	2.1	0.1	0.0	0.0
	21-Jul-04	19.4	0.0	0.3	0.0
	11-Aug-04	0.0	1.4	0.0	0.0
	25-Aug-04	5.6	3.3	0.0	0.2
Trial 3	13-Oct-04	0.0	0.0	0.0	0.0
	27-Oct-04	11.6	1.7	0.0	0.0
	10-Nov-04	8.2	0.0	0.0	0.0
	24-Nov-04	8.3	5.4	0.0	0.0
	15-Dec-04*	5.4	2.7	0.0	0.0
Trial 4	09-Feb-05	1.1	1.1	2.0	0.0
	23-Feb-05	0.0	0.0	0.0	0.0
	09-Mar-05	0.0	0.0	0.0	0.0
	23-Mar-05	4.2	1.1	0.0	0.0
	06-Apr-05*	5.5	1.4	0.0	0.2
	Average	4.1	1.1	0.2	0.1
	SD	5.2	1.5	0.5	0.2

*Additional sampling week was done for Trials 3 and 4.

Ammonia emission

For each monitored week during the four trials, ammonia concentrations were measured continuously in each room at two locations: at the ventilation inlet and at the exhaust airstream. From these ammonia readings and the corresponding ventilation rate in the room, the ammonia emission rates were calculated for each room using Equation 3. Table 7 summarises the weekly average ammonia concentrations and the average ammonia emission rate for the two rooms. Significant levels of ammonia were measured in the incoming inlet air for both rooms (mean = 5.3 ppm, SD = 1.4 pm); this was attributed to possible recirculation of air exhausted from the fans into the supply air coming into the barn as well as from possible back draft of ammonia from adjacent rooms into the barn attic.

The average ammonia concentrations measured at the inlet of the two rooms were similar. However, a comparison of the weekly average ammonia concentrations measured at the exhaust of the two rooms showed significantly ($p<0.05$) higher mean concentration in the scraper room (11.9 ppm, SD = 2.1 ppm) than in the control room (10.4 ppm, SD = 1.9 ppm), although the mean difference was smaller than the indicated accuracy of the ammonia analyser. Using Equation 1, calculation of the percent reduction in the corresponding ammonia emission values (control vs. scraper) showed an average reduction of –36%, indicating that ammonia emissions were higher in the scraper room compared to the control room (Table 7). A plot of the ammonia emission values for the two rooms confirmed this observation (Fig. 19).

This can be attributed to the well-documented observation in previous studies that scraper systems can promote ammonia emissions by leaving a film of excreta at the bottom of the channel. A similar occurrence was evident from the data collected in this study; the scraper system was effective in controlling H_2S levels, but the scraping process enhanced ammonia release from manure pit surfaces.

Table 7. Summary of weekly average values for ammonia measured in the control and scraper rooms.

Trial No.	Date	Inlet concentration (ppm)		Exhaust concentration (ppm)		Average emission (g/hr)		Emission reduction (%)
		Control	Scraper	Control	Scraper	Control	Scraper	
Trial 1	8-12Mar04	4.5	4.4	9.1	11.6	9.7	14.9	-53.6
	22-26Mar04	5.3	5.3	12.8	14.1	13.3	16.2	-21.4
	5-9Apr04	6.6	6.6	11.7	13.1	23.4	20.9	10.9
	19-23Apr04	3.4	3.4	7.1	7.9	19.8	22.8	-15.0
Trial 2	28Jun-2Jul04	5.9	5.9	7.3	8.0	9.6	15.3	-59.3
	19-23Jul04	7.7	7.7	10.6	11.7	23.2	32.3	-39.2
	9-13Aug04	7.3	7.3	10.1	12.4	19.6	37.6	-91.8
	23-27Aug04	7.3	7.3	10.9	13.0	23.3	41.9	-79.5
Trial 3	11-15Oct04	5.3	5.3	8.9	10.6	9.4	11.9	-26.9
	25-29Oct04	3.8	3.8	9.3	11.2	10.8	14.4	-33.3
	8-12Nov04	4.0	3.9	14.1	11.7	22.0	13.8	37.5
	23-26Nov04	2.6	2.6	10.9	14.5	14.4	20.4	-41.9
	12-14Dec04*	4.7	4.7	12.6	16.5	15.3	26.2	-71.0
Trial 4	7-11Feb05	4.8	4.8	12.1	11.7	7.1	6.5	8.5
	21-25Feb05	5.2	5.3	10.4	13.2	5.1	7.5	-45.3
	7-11Mar05	4.9	5.0	8.7	10.7	6.9	9.3	-33.5
	21-24Mar05	5.3	5.4	10.7	11.5	8.5	10.3	-20.8
	4-7Apr05*	7.0	7.1	9.6	10.4	11.1	18.4	-65.3
	Average	5.3	5.3	10.4	11.9	14.0	18.9	-35.6
	SD	1.4	1.4	1.9	2.1	6.3	10.0	33.1

*Additional sampling week was done for Trials 3 and 4.

From a health and safety perspective, the increase in ammonia production rate in the scraper room did not compromise the worker safety. The average ammonia concentration in the room was no more than 1.5 ppm higher than in the control room, with a maximum concentration of 22.6 ppm measured during Week 2 of Trial 2. In fact, the maximum ammonia concentration measured in the control room was higher (28.3 ppm during Week 5 of Trial 3), but this could also be attributed to the high levels of ammonia measured at the inlet during that week. Compared to the 25-ppm 8-hr contamination limit value for ammonia (Saskatchewan Occupational Health and Safety Regulations, 1996), the average scraper room ammonia concentrations were still lower than this limit value, despite the presence of significant levels of ammonia in the incoming air.

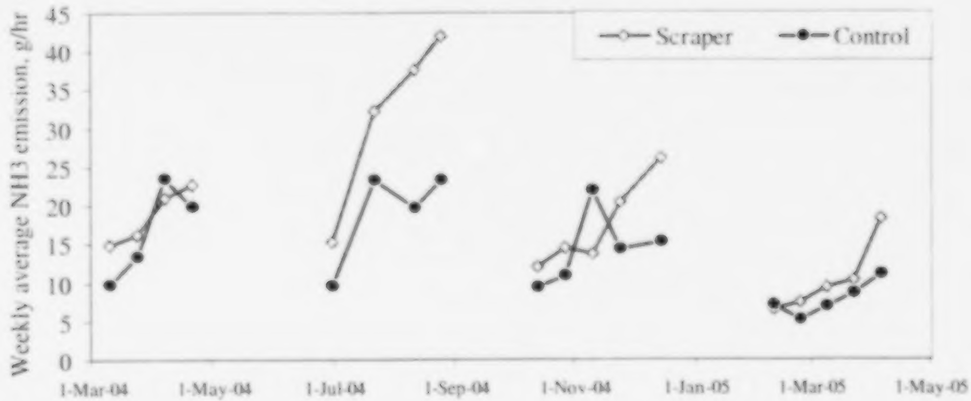

Figure 19. Plot of weekly average ammonia emission rates for the control and scraper rooms.

The previously reported impact of scraper systems on ammonia levels was precisely the reason that the removable retaining-wall set-up was installed as part of the scraper system. This part of the study was designed to examine the impact of retaining the liquid slurry component in the manure pit while scraping out the manure solids daily on the ammonia levels in the scraper room. By retaining more liquid, it was expected that ammonia formation will be diminished and that less emissions would accrue from the slurry mixture instead of from fresh urine puddle deposited at the bottom of the channel. During each trial, the scraper was operated in one direction for one monitoring week, then the direction was reversed on the subsequent monitored week. Thus, ammonia emissions data were collected on alternating scraper direction between the successive monitoring weeks, which corresponded to either removing the manure mixture daily (downslope direction) or retaining the liquid slurry in the manure pit while scraping out the manure solids (upslope direction). Table 8 summarizes the weekly average ammonia emissions from the scraper room for the two scraping directions. Although the mean value for upslope direction (21.0 g/hr, SD = 10.3) was higher compared to the downslope direction (16.3 g/hr, SD = 9.6), statistical comparison of the emission values showed no significant difference ($P>0.05$) between the two scraping directions, indicating that the procedure had no significant impact on the ammonia emissions from the room, but in fact may have the opposite anticipated effect. In other studies, it was shown that maintaining a layer of standing water in the manure channel after scraping counteracted this effect on ammonia; results from this current study indicate that maintaining a slurry layer at the bottom of the manure channel may not have the same effect.

Cost analysis

The cost of installing and operating the scraper system in the production room was documented to demonstrate the feasibility of the system as an option for controlling H_2S levels. The main cost items were the scraper system itself (scraper blade, pulleys, cables, motor, controllers) and installation of the system (room retrofit). Because the system was installed as an experimental set-up, additional costs were incurred (e.g., false flooring, removable wall, end tubs, etc.) that may not be required if a similar system was installed in a commercial production room. The overall system cost was $2823 for the scraper system, $1970 for installation labour, and $1710 for materials and parts (e.g., concrete, wiring, etc.). Operation required about 1 hr per week (less than 10 min per day) while maintenance required about 3 hrs cleaning of the manure channel every two weeks to keep the blade running on the channel surface smoothly. Throughout the operation of the scraper (15 months), no major breakdown of the system was experienced and the replacement parts required were nuts and fittings amounting to about $50.

Table 8. Summary of weekly average NH_3 emissions in the scraper room during tests with downslope scraping direction to remove manure mixture daily and upslope scraping direction to remove manure solids and retain liquids.

Downslope direction			Upslope direction		
Trial No.	Date	NH_3 emission, g/hr	Trial No.	Date	NH_3 emission, g/hr
Trial 1	8-12Mar04	14.9	Trial 1	22-26Mar04	16.2
	5-9Apr04	20.9		19-23Apr04	22.8
Trial 2	28Jun-2Jul04	15.3	Trial 2	19-23Jul04	32.3
	9-13Aug04	37.6		23-27Aug04	41.9
Trial 3	11-15Oct04	11.9	Trial 3	25-29Oct04	14.4
	8-12Nov04	13.8		23-26Nov04	20.4
Trial 4	7-11Feb05	6.5		12-14Dec04	26.2
	7-11Mar05	9.3	Trial 4	21-25Feb05	7.5
	Average	16.3		21-24Mar05	10.3
	SD	9.6		4-7Apr05	18.4
				Average	21.0
				SD	10.3

Conclusions

Module 1 - A remote manure plug pulling system was successfully developed. Results show that H_2S exposure of the worker in the alleyway was eliminated when the plug was pulled, compared to an exposure of up to 68 ppm inside the room where the plug was pulled. The system was designed in a manner such that if the plug popped out due to back pressure in the sewage lines, the plug would slide back into place when the manure drained from the channel and would not remain open, thus preventing backdraft of H_2S into the room from the sewage lines. The system was also designed for existing manure pits, minimizing the system implementation costs.

Module 2 - A laboratory study was carried out to measure the effectiveness of sprinkling water to reduce H_2S gas from the air. Several water treatments were tested, as well as different spraying nozzles and flowrates. By sprinkling water with a pH 9 at 200 kPa using a hollow cone nozzle, a 79% reduction in H_2S gas was measured. The effect of water temperature was also verified; with colder water (15°C), the maximum H_2S concentration was lower by 23% compared to using warmer water (25°C).

A subsequent study was carried out using agitated manure as the source of H_2S to test the optimum treatment combinations developed in the laboratory study. However, use of the Draeger Pac III monitor to measure the exhaust air from the agitated manure generated results that are inexplicable at the present time. Sprinkling water over the manure headspace increased the H_2S concentration, even when the manure was not agitated. Based on the results from the laboratory study and from literature review, the anticipated result was that the sprinkled water will reduce the levels of H_2S, thus the observed results for this part of the study were unexpected.

Additional work was done to try to explain the results from the study, including contacting various individuals; it was suggested that the monitor readings be compared with different methods of H_2S measurements. In an effort to check the Draeger Pac III results, an air sample was collected from both agitated manure with no water sprinkled, and from agitated manure with water sprinkled. This air sample was tested using the Draeger Pac III, chemical detector tubes, and gas chromatography. The results showed that the chemical detector tubes and gas chromatography results were similar, and the reading from the Draeger Pac III for the same sample was several times higher. Using these alternative methods of measurements, it was also confirmed that when water was sprinkled, the concentration of H_2S increased.

Considering the time and funding available, we could not go further in trying to explain the reaction of the electrochemical sensor monitors, and we could not utilize a different method of measuring the H_2S from the manure aspect of the sprinkling study. In addition, further work would need to be done to ensure that the setup using the 170-L barrel and manure adequately represents what happens in a manure pit, and to explain why we saw an increase of H_2S using the four methods of measurements considered (Pac III, chemical tubes and gas chromatography). However, in the absence of other gases, the laboratory study was successful in reducing the H_2S levels by 79%, and we would expect to see a similar reduction in the manure pit. Currently, the measuring techniques need to be reinvestigated, as well as the experimental setup to ensure that the results are representative of what is happening in the manure pit.

Further investigation and testing is required to explain these results, which was outside the scope of this current project. As a result, the manure aspect of Module 2 was not completed as initially outlined in the proposal, as a need now exists to ensure that proper measuring techniques are available in order to properly assess the response of the engineering controls to the presence of H_2S gas.

Module 3 – A manure scraper system was installed in a full-scale grower-finisher room in PSCI and evaluated by comparing the H_2S and ammonia levels in the experimental (scraper) room with another grower-finisher room operated under normal production conditions (control). Four trials were completed, corresponding to four production cycles for the rooms. The maximum H_2S concentrations measured in the scraper room were lower by an average of 85 to 91% compared to the control room. The 15-ppm contamination limit value was exceeded once in the scraper room, while the maximum H_2S levels in the control room exceeded the limit value nine times during the four trials. The 15-min time-weighted average (TWA) values in the scraper room were also well below the contamination limit value, and on average about 96% lower compared to the control room. Overall results demonstrated the effectiveness of the scraper system in reducing H_2S exposure of swine barn workers.

Significant levels of ammonia were measured in the air entering both rooms (average of 5.3 ppm), which was attributed to possible recirculation of exhaust air into the inlets and backflow of gases from adjacent rooms to the attic. Comparison of the weekly mean ammonia concentrations in the two rooms showed higher levels in the scraper room (11.9 ppm) than in the control room (10.4 ppm), although all measured values were below the 25-ppm 8-hr contamination limit value for ammonia. Consequently, the weekly average ammonia emission levels in the scraper room were higher by an average of 36% compared to the control room. This was attributed to the enhanced ammonia release from manure pit surfaces on which an active layer of excreta was left by the scraper. Retaining the liquid slurry in the manure pits to address this increased ammonia release showed no significant impact on the ammonia emissions. Although the increase in ammonia levels associated with the scraper system is not sufficient to compromise worker safety, further investigation is needed to mitigate this effect on ammonia, thus consolidating the overall benefit of using a scraper system to reduce worker exposure not only to H_2S but possibly to other gases as well.

Recommendations

Based on the results of this project, the following recommendations can be made:
1. the plug-pulling system was shown to be a straightforward and effective method for eliminating worker exposure to H_2S, thus, its adoption is strongly recommended. Furthermore, the system can be easily adapted to existing barns, its operation is simple, and requires minimal capital investment, thus making it a cost-effective control measure.
2. the water-based spray treatment method was shown to be potentially effective under laboratory conditions. However, this method needs further investigation before it can be recommended for application in swine barns.
3. the scraper system was demonstrated to be highly effective in controlling H_2S levels. It can be recommended as a control measure for minimizing risk of worker exposure to H_2S, particularly if combined with other measures such as diet manipulation to eliminate the observed effect on ammonia. However, this method requires substantial capital investment, thus its adoption must be justified not only from the point of view of reducing worker exposure to H_2S, but also from other benefits accrued from improvement in overall indoor air quality and for facilitating manure handling operations.

Project Activities

Module 1

January through April 2002 – September through December 2002:
- Design of the improved manure pit plug system by the two undergraduate ABE students.

September through June 2002:
- Design and fabrication of the test bench equipment for manure pit plugs.
- Beginning of the testing program for the improved manure pit plug design.

June 2003 – December 2003:
- Completion of the testing program for the improved manure pit plug design.
- Analysis of the experimental results.
- Writing of the final report.

Module 2

March through July 2003:
- Planning of the laboratory-scale experiment.

July 2003 through February 2004:
- Completion of laboratory and bench-scale experiments.

September 2003 through March 2004:
- Analysis of the water-based liquid spray efficacy.
- Writing of the final report.

Module 3

October 2003 through February 2004:
- Design and installation of manure scraper system.

February 2004 through February 2005:
- Testing of manure scraper system.

January through April 2005:
- Analysis of the experimental results.
- Writing of the final report.

Potential impact on the swine industry

The results from this study will help to identify potential solutions to reduce the levels of H_2S currently seen in swine barns when manure is handled. The engineering controls developed in this project can be implemented in existing swine barns, and thus reduce worker exposure to H_2S. These project results will help in promoting wide adaptation of measures that enhance safety and well-being of workers in the swine industry, thereby contributing to the recognition of the industry as responsible and reactive employers. By helping to improve occupational safety and control emissions of gaseous contaminants to the environment, then the project results will also contribute towards sustainability and growth of the Saskatchewan swine industry.

Information of benefit to other sectors and government

Information gained from this project can also be useful in other livestock sectors with similar issues concerning hydrogen sulphide. This study highlighted the need for additional work to be done on developing methods to control the risk of exposure of workers to H_2S. Appropriate government regulations must be in place to ensure that commercially available H_2S monitors meet certain standards to ensure adequate protection of workers when performing tasks that can potentially lead to H_2S exposure. Similar control methods for reducing worker risks during manure handling tasks outside the barn such as transferring manure from the barn to storage tanks or manure trucks, evacuating manure storage facilities, and land application of manure, must be explored and given continued research funding support.

Personnel

Summarized in Table 9 is the breakdown of ADF funds provided for Module 3 of the project for the salaries and wages of persons involved, the amount of time spent on project work, and salary paid.

Table 9. Summary of personnel salaries and wages for Module 3 of the project, funded by ADF.

Personnel	No. of months	%Time	Salaries / wages
Research Technician (R. Fengler)	24.0	50%	$ 42,725.52
Research Assistant (S. Christianson)	10.0	25%	10,761.66
Contract labour (various)	2.0	100%	10,055.96
		Total paid =	$ 63,543.14

Equipment

The major equipment acquired for Module 3 is the scraper system, which was installed in the experimental room. The main components of the scraper system were purchased from a manufacturer of similar agricultural equipment in Québec, and adapted for installation in the selected grow-finish room at PSCI Floral facilities.

Project Developed Materials

With respect to Module 1 of the current project, a capstone design report was written and presented by Mr. Mathew Marshall and Mr. Tyrell Bjarnason to the Agricultural and Bioresource Engineering Department at the College of Engineering at the University of Saskatchewan.

For both Modules 1 and 2, Dr. Stéphane Lemay presented an article titled 'How Can I Control Hydrogen Sulphide in my Barn' at the 2004 Banff Pork Symposium, and Ms. Shala Christianson presented a poster titled 'Engineering Controls to Reduce Hydrogen Sulphide in Swine Barns' at the same symposium. An article was published in the PSCI 2003 Annual Report titled 'Engineering Controls to Reduce Hydrogen Sulphide Exposure in Swine Housing'. In addition, a paper based on the Module 2 activities was written and a presentation was made at the 2004 ASAE/CSAE Conference held in Ottawa on August 2004.

With respect to Module 3, a paper based on the preliminary results was written and presented at the North Central ASAE/CSAE Conference in Winnipeg on September 2004. A poster based on this module was also presented at the 2005 Banff Pork Seminar last January 18-21, 2005, at Banff, Alberta. An article on the scraper study was published in the 2004 PSCI Annual Research Report, as well as in the Winter 2005 issue of the PSCI Centred on Swine Newsletter. The final results of the study will be presented at the 2005 North Central ASAE/CSAE Conference which will be held in South Dakota on September 2005.

A copy of papers, posters and other publications are attached in Appendix I.

Project Photos

Additional pictures are included in this section to supplement the photos in this report.

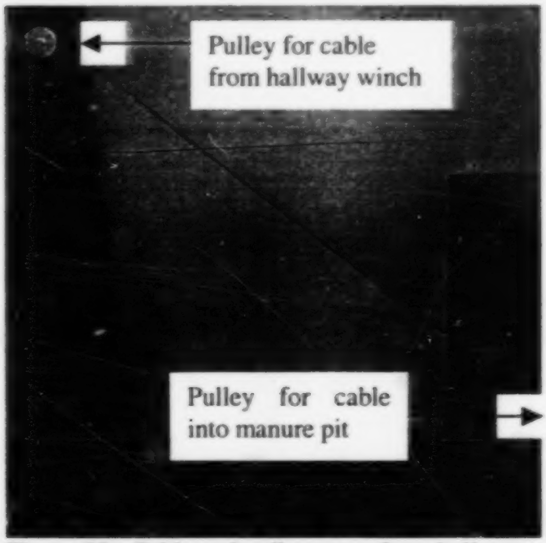
Pulley for cable from hallway winch
Pulley for cable into manure pit

Figure 20. Cable and pulley setup from hallway to pen.

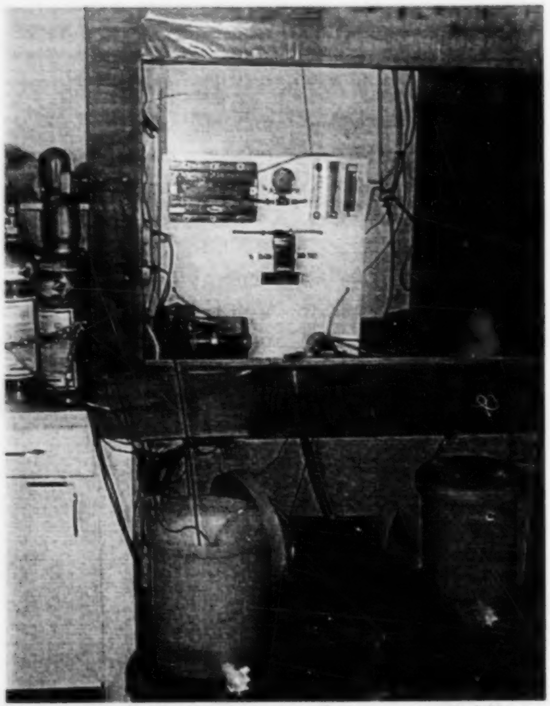

Figure 21. Laboratory setup for water sprinkling experiment.

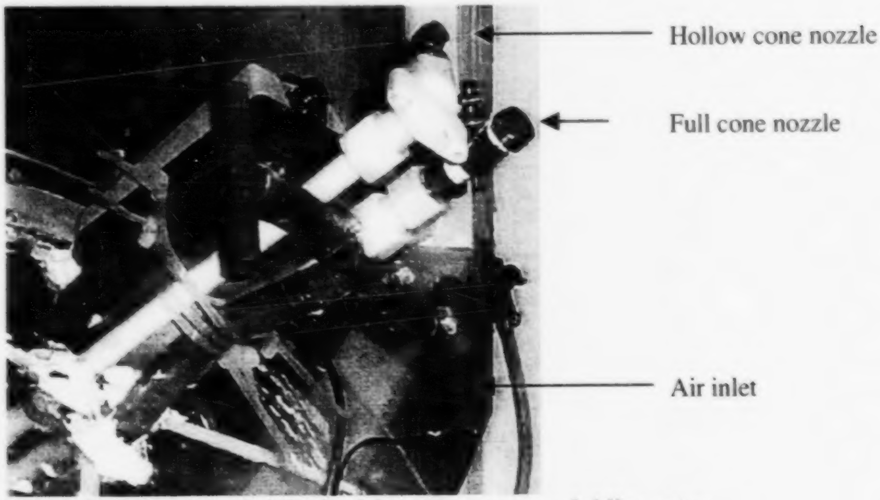
Hollow cone nozzle
Full cone nozzle
Air inlet

Figure 22. Nozzles, air inlet for laboratory water sprinkling setup.

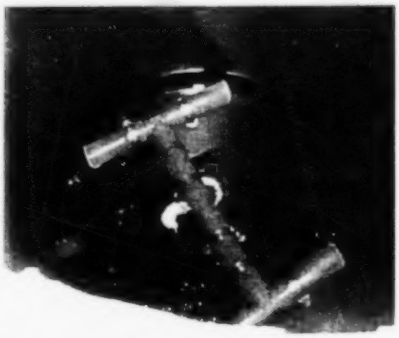

Figure 23. Hydrogen sulphide inlet at base of PVC pipe for laboratory water sprinkling.

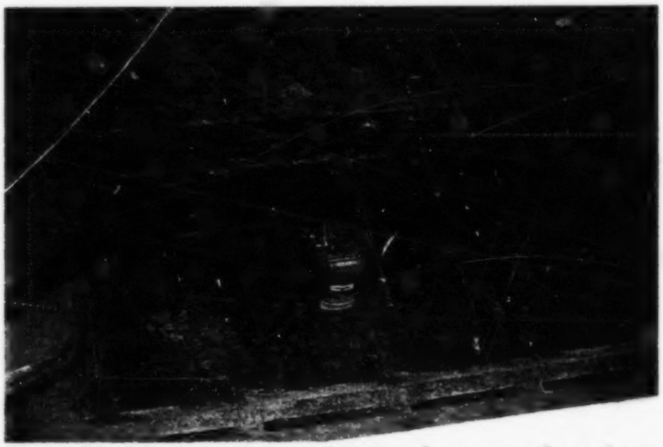

Figure 24. Manure pump used to transfer manure from the manure pit to the mixing tub.

Figure 25. Transporting 170-L barrels containing manure to experimental room.

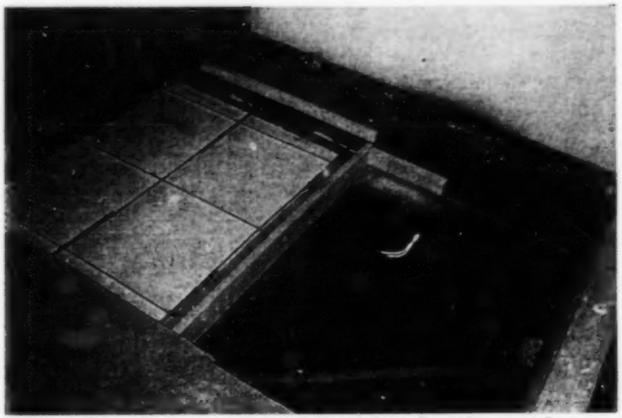

Figure 26. Construction of the false flooring surface and the accumulation tub at the end of the manure pit.

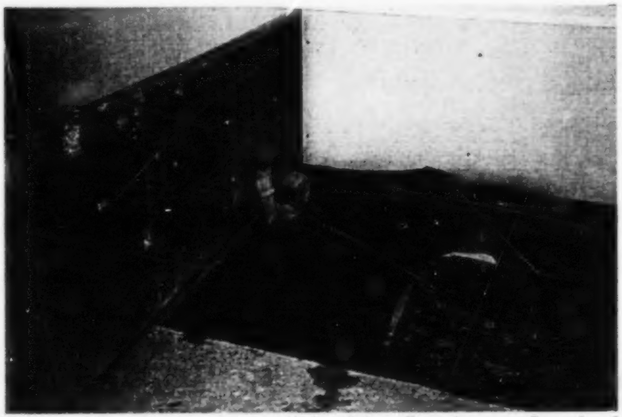

Figure 27. Construction of the false flooring surface in the manure pit. The scraper blade ran over this surface to push the manure to the accumulation tub at the end of the pit.

■ Acknowledgement

For the 2004 Banff Pork Symposium, acknowledgement of the support of ADF was made in the article titled 'How can I Control Hydrogen Sulphide in my Barn?". In addition, the oral presentation by Dr. Lemay and the poster presentation by Christianson et al. (2004) at the same conference also acknowledged the support of ADF. The same recognition of ADF support was also made in subsequent publications and presentations based on this project, including the 2004 ASAE/CSAE Conference, 2005 Banff Pork Seminar, 2004 PSCI Annual Research Report, PSCI Centred on Swine Newsletter, as well as in the presentation for the upcoming 2005 ASAE/CSAE Conference.

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■ Appendix I

Project Developed Materials

1. "How can I control hydrogen sulfide in my barn?" - article presented at 2004 Banff Pork Seminar
2. "Controls to reduce hydrogen sulphide in swine barns" – poster presented at 2004 Banff Pork Seminar
3. "Engineering controls to reduce hydrogen sulphide exposure in swine housing" – article published in PSCI 2003 Annual Report
4. "Engineering controls to reduce hydrogen sulphide exposure of workers in swine buildings" – Paper No. 044133 presented at 2004 ASAE/CSAE Annual International Meeting
5. "Evaluation of a manure pit scraper system for controlling hydrogen sulfide gas in swine barns" – Paper No. MB04-504 presented at 2004 North Central ASAE/CSAE Conference
6. "Evaluation of a manure pit scraper system for controlling hydrogen sulfide gas in swine barns" – Powerpoint presentation for 2004 North Central ASAE/CSAE Conference
7. "Controlling hydrogen sulfide gas in swine barns with a manure pit scraper system" – poster presented at 2005 Banff Pork Seminar
8. "Engineering controls to reduce hydrogen sulphide exposure in swine barns" - article published in PSCI 2004 Annual Research Report
9. "Evaluation of a manure pit scraper system for controlling hydrogen sulfide gas in swine barns" – article published in PSCI Centred on Swine Newsletter

How can I Control Hydrogen Sulphide in my Barn?

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▪ Introduction

Hydrogen sulphide (H_2S) is a life threatening gas produced by the anaerobic degradation of liquid manure. As most swine barns are equipped with gutters that accumulate manure for a period of time, H_2S can be released while performing common tasks that involve manure flow or mixing. In most cases, H_2S exposure may not result in death, but short and long-term effects can have impacts on the health and well being of the exposed person.

Saskatchewan Labour regulates H_2S exposure in the Occupational Health and Safety Regulation and stipulates that at no time should a person be exposed to an average of 10 ppm of H_2S for a period of 8-h (TWA: 8 hour time weighted average exposure limit) and an average of 15 ppm for a period of 15-min (STEL: 15-min time weighted average contamination limit). Saskatchewan Labour does not have a defined ceiling value for H_2S, but defines the level of H_2S that is immediately dangerous to life or health (IDLH) at 100 ppm, a level at which no one should even be exposed to.

Chénard et al. (2003) studied six pig farms to assess the exposure of the barn workers to H_2S while pulling pit plugs and power-washing production rooms. Results indicated that plug pulling generated high concentrations of H_2S reaching 1,000 ppm in some cases. All of the farms used in this study had plug pulling events that exceeded limits defined by the Occupational and Safety Regulations of Saskatchewan. Also, the H_2S released when a plug was pulled did not follow a predictable pattern both over time, and within the room. Power washing generated lower H_2S concentrations than plug pulling but workers were exposed for a longer time period.

Based on the study by Chénard et al. (2003), swine barn workers may be exposed to H_2S concentrations that exceed acceptable limits when pulling pit plugs and power-washing rooms. The authors also concluded that further research is needed to improve the building design and manure management systems, and to develop practical engineering controls for preventing the H_2S exposure in swine buildings. This paper provides an update on the control technologies under development at PSC.

▪ Objectives

The main goal for the current project is to develop low cost systems that will prevent or reduce worker exposure to high H_2S concentration during plug pulling events in swine buildings. The three specific objectives are presented under three different project modules:

Module 1

To design and develop a pit-plug pulling system that allows the plugs to be opened from a remote location, prevents backflow of manure or gases when the plugs are closed, and is adaptable to existing in-barn manure management systems.

Module 2

To determine reduction of H_2S gas when tap water is sprinkled, along with tap water with a buffer to increase pH, and tap water combined with hydrogen peroxide, essential oils or ferric sulphate. The water temperature and application rate are also investigated.

Module 3

To design and develop a pit scraper system to remove swine manure from the barn on a daily basis, and to evaluate the reduction of H_2S. The system will be developed and retrofitted in an existing barn with liquid manure handling systems.

Considering that Modules 1 and 2 have been completed and Module 3 is being initiated at the current time, this report focuses primarily on Modules 1 and 2 of the project.

▪ Experimental Approach

Module 1 – Pit puller system

A pit plug was designed and a bench-scale prototype of the system was built. The extended cone plug was selected, as it met the design criteria of low cost, ease of installation, safety, plug popping control and formation of a consistent seal on the sewer pipe hole. This design also minimized the manure flow restriction to the hole. A cage was also designed to prevent the plug from coming too far out of the hole (**Figure 1**). With this cage in place, if the plug is pulled or if it pops due to a build-up of pressure in the lines, the funnel-shaped extension on the plug will remain in the hole and guide the plug back into the hole to reform the seal.

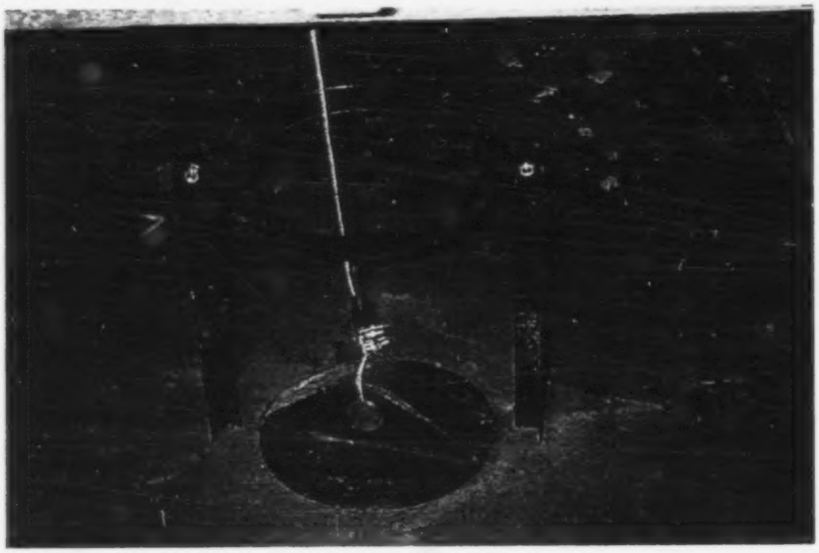

Figure 1. Plug pulling apparatus including cage underneath the slats.

The operating system for plug pulling was selected based on the following criteria: initial cost, operating cost and maintenance of the plug pulling system. The pulley system with optional winch was selected as the preferred method of mechanical plug pulling (**Figure 2**) amongst the following systems: an air pressure system, electric motor apparatus and pulley system.

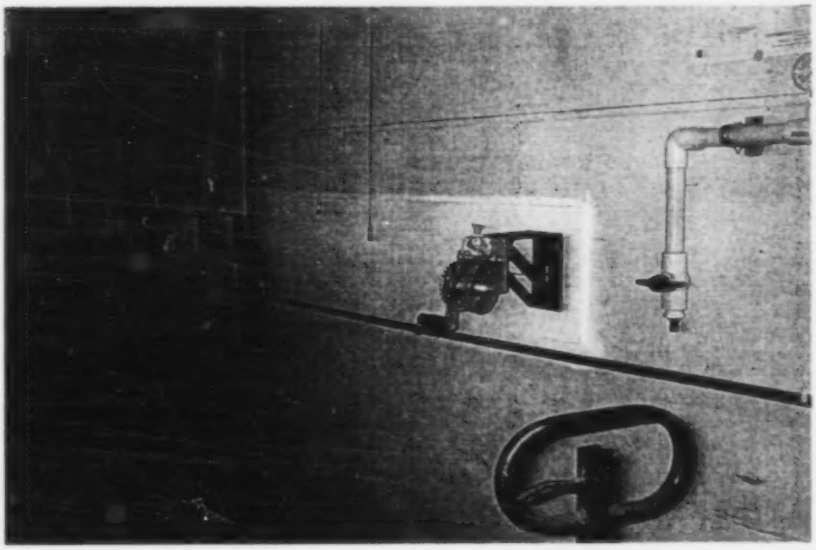

Figure 2. Pit plug pulling winch system in alleyway. There are two winches operating two separate systems in two different rooms.

Module 2 - Bench Scale Experiments on Hydrogen Sulphide Abatement by Water-Based Liquid Spraying

A laboratory apparatus was designed (**Figures 3 and 4**) to simulate H_2S peak concentrations observed during plug pulling events in barns. This setup consisted of a 0.9 m high PVC tank in which H_2S gas at a concentration of 1000 ppm was injected. The head space of the tank was ventilated so by injecting a known amount of H_2S in the tank, it was possible to recreate an H_2S concentration pattern at the tank air exhaust similar to what was observed in barn conditions during Chénard et al. (2003) study. The tank was also equipped with a nozzle port to spray water solution while the H_2S was injected. Various additives could be added to the water in the open reservoir, and the treatments were sprayed at different flow rates.

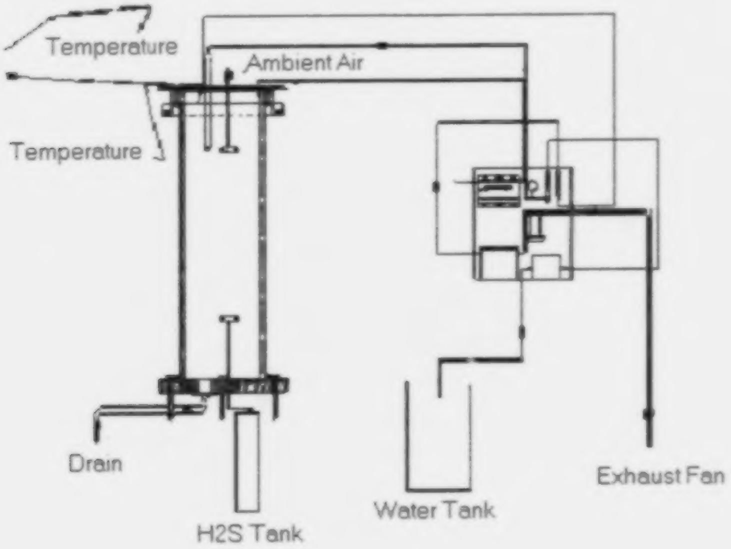
Temperature
Ambient Air
Temperature
Drain
H2S Tank
Water Tank
Exhaust Fan

Figure 3. Overall schematic of hydrogen sulphide laboratory setup.

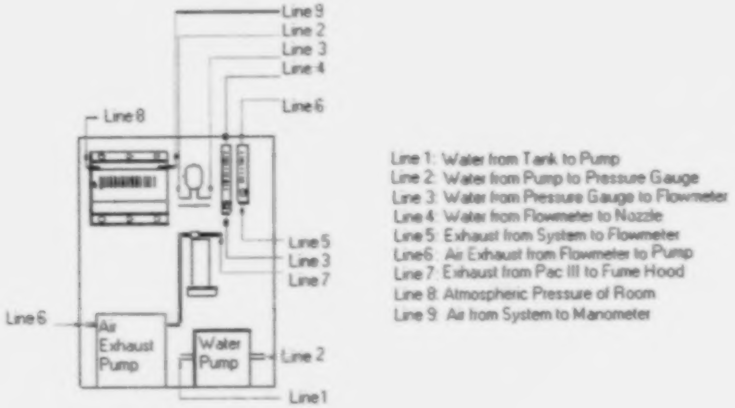
Line 9
Line 2
Line 3
Line 4
Line 8
Line 6
Line 5
Line 3
Line 7
Line 6
Air Exhaust Pump
Water Pump
Line 2
Line 1
Line 1: Water from Tank to Pump
Line 2: Water from Pump to Pressure Gauge
Line 3: Water from Pressure Gauge to Flowmeter
Line 4: Water from Flowmeter to Nozzle
Line 5: Exhaust from System to Flowmeter
Line6: Air Exhaust from Flowmeter to Pump
Line 7: Exhaust from Pac III to Fume Hood
Line 8: Atmospheric Pressure of Room
Line 9: Air from System to Manometer

Figure 4. Diagram of hydrogen sulphide laboratory system operation.

▪ Results to Date

Module 1 - Trial Results

A prototype of the plug system was installed in two full-scale grower-finisher rooms at PSC in the spring of 2003, and its operation is currently being tested and monitored. Nine pulling events have been recorded to date, with the H_2S concentration measured in both the room where the plug was pulled, and in the alleyway where the winch was located.

The maximum H_2S concentration from all the monitored events was 68 ppm, with corresponding concentrations in the alleyway near the winch at 0 ppm. This indicates the system has proven to be very effective in protecting the worker from being exposed to H_2S. The cost of implementing this design in a 4-plug room is estimated to be $280, which includes the winch.

Module 2 – H_2S Abatement With Water-Based Liquid Spraying

Preliminary work was done to determine the injection rate and time needed for the H_2S gas to reach 180 ppm inside the pipe. This injection rate and time were then used to add H_2S to the pipe for the sprinkling study.

Based on preliminary results using the various treatments (three different nozzles, three operating pressures, and five water treatments), the final experiment used only the hollow and the initial full cone nozzles, with three operating pressures (10, 20, 30 psi) and three water treatments (tap water, tap water with an increased pH 9 and tap water with hydrogen peroxide). Three repetitions were made for each treatment.

The results from this trial are presented in **Figure 5**. There were no significant differences between the blocks ($p>0.05$), and there were significant differences among both water type and nozzle type ($p<0.05$). There was also a significant difference between the water*nozzle*pressure interaction ($p<0.05$), which tells us that each treatment was significantly different from the others. The best reduction of H_2S occurred when the hollow cone nozzle was used at 30 psi using water at a pH of 9, resulting in a 79% reduction of the maximum H_2S. Use of a full cone nozzle at pressures 10, 20 and 30 psi resulted in high levels of H_2S reduction as well, but the water volume used was much higher than for the hollow cone (18 – 63% more water).

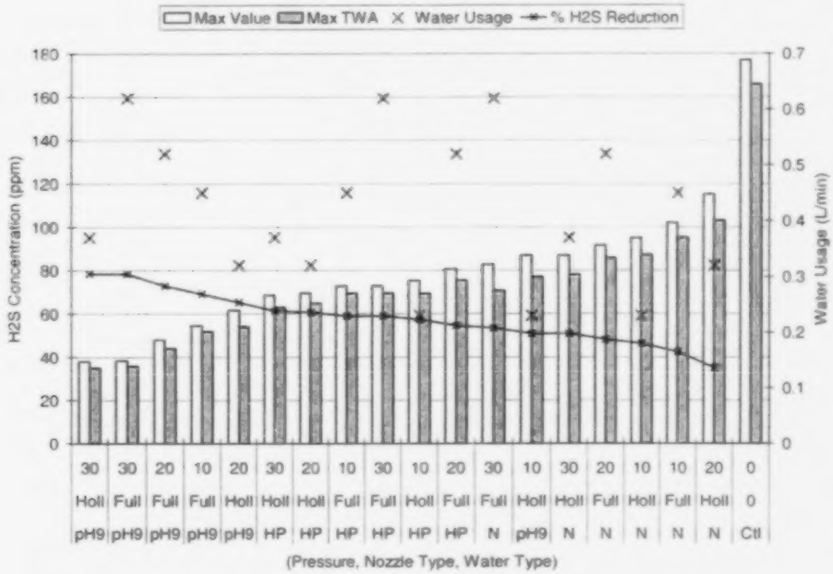

Figure 5. Summary of results (Pressures – 10, 20, 30 psi; Nozzle Types – hollow and full cone; Water Type – normal water, water at pH 9 and water with hydrogen peroxide added).

Calculations show that if the hollow cone nozzle was used in a grower-finisher swine manure pit to sprinkle water over the entire pit for 15 min. while the pit was draining, the total volume of water used would be in the range of 5 – 8% of the total manure pit volume (1.0 – 1.6 m^3). However, it is likely that spraying would not have to be performed over the entire manure pit, and total sprinkling time could be shorter than 15 min., so the addition of water corresponding to 5-8% is likely a conservative estimate that could be reduced in the final design.

Further studies will be done using the top three optimum treatment combinations on reducing H_2S from agitated swine manure. Sixteen 45-gal barrels will be used for this study, and manure will be used from a grower-finisher room. Since the hollow cone nozzle saw a good reduction of H_2S (51 – 79% reduction) with tap water at a pH of 9 and used much less water than the full cone nozzle, the subsequent study using manure as a source of H_2S will investigate the use of hollow cone nozzles with tap water at a pH 9 at 10, 20 and 30 psi.

Summary

Swine workers may be at risk of being exposed to high H_2S concentrations when pulling pit plugs in barns. Three engineering controls are being studied at PSCI:

- a remote plug puller system
- a water based sprinkling system
- an adapted manure scraper

At this time, both the remote puller and the sprinkling systems look promising to control the H2S exposure of workers at a low cost. Further experiments will be completed with the water spraying system and the manure scraper concept will be implemented at PSCI over the winter of 2004.

Acknowledgments

The authors would like to acknowledge the financial contribution of Sask Pork, PIC Canada and ADF, who are supporting this research. Thanks must also be given to Saskatchewan Agriculture and Food, Sask Pork, Alberta Pork and Manitoba Pork for strategic funding to the research program at PSCI.

References

Chénard, L., S.P. Lemay and C. Laguë. 2003. Hydrogen sulfide assessment in shallow-pit swine housing and outside manure storage. Journal of Agricultural Safety and Health **9**(4): 285-302.

Controls to reduce hydrogen sulphide in swine barns

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Previous studies have shown that a serious hazard in swine buildings is the presence of hydrogen sulphide (H_2S) in the manure. Hydrogen sulphide forms in the manure pit by anaerobic degradation, and as long as the manure is not agitated most of the H_2S produced remains dissolved in the liquid manure. When barn workers perform manure-handling tasks, such as pulling manure pit plugs, they can be at a high risk for exposure to H_2S that is released from the agitated manure.

The goal for this project is to develop and study control methods that may be implemented in current swine barns to reduce H_2S levels during manure handling practices. Three control methods are investigated, including 1) a remote plug pulling system; 2) water-based sprinkling in the manure pits; and 3) use of a manure scraper.

The remote plug pulling system consists of a winch outside the swine room that pulls a cable connected to the manure plug, allowing the worker to pull the plug from outside the room. To date, the design works well and effectively reduces the worker's exposure to H_2S. The water-based sprinkling system has shown to reduce the maximum levels of H_2S by up to 79%, depending on the nozzle type, water characteristics and flowrates. The manure scraper aspect will be studied in the winter of 2004.

Implications:
Three H_2S control systems that can be retrofitted into an existing barns under liquid manure management were investigated. A system that pulls the manure plugs from outside the swine room is effective at reducing worker exposure to H_2S, as is sprinkling a water-based solution over the H_2S gas emitted from agitated manure.

Engineering Controls to Reduce Hydrogen Sulfide in Swine Barns

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The Message

- Three control systems that can be retrofitted into an existing barn under liquid manure management to reduce hydrogen sulphide (H_2S) production and emission problems are being developed and examined. The three options being investigated are: 1) a remote pulling system for manure plugs, 2) spraying a water-based solution on the manure during emptying of pits, and 3) retrofitting a manure scraper into an existing pull-plug manure pits. These systems are evaluated in terms of their potential at reducing both worker and animal exposure to H_2S.

Introduction

- Hydrogen sulfide is a gas produced by anaerobic degradation of liquid swine manure, and studies have shown that H_2S is a serious health hazard in swine buildings. Research is needed to develop practical engineering controls for limiting or preventing H_2S exposure in swine buildings.

Objectives

- The general objective for this project is to develop and study control methods that may be implemented in existing swine barns to reduce H_2S levels during manure handling operations. Three control methods are investigated: 1) a remote plug pulling system; 2) water-based sprinkling in the manure pits; and 3) use of a manure scraper.

Methods

- *Project 1 – Remote plug pulling system:*
  - An extended cone plug and a plug height stop was designed to prevent the plug from coming entirely out of the hole, and a pulley system with a winch was selected as the preferred method of mechanical plug pulling.
  - A prototype of the design was tested in a laboratory setting, and is currently being tested in two full-scale grower-finisher rooms at PSC.
  - The H_2S concentration was measured simultaneously in the room where the plug was pulled and in the alleyway where the winch was located.

- *Project 2 – Water-based Sprinkling:*
  - A laboratory apparatus was designed to simulate peak H_2S concentrations observed during plug pulling events in barns. This setup is made of a 0.9 m high PVC tank in which H_2S gas at a concentration of 1000 ppm is injected, as in Figure 1.
  - Water with different properties (normal water, water with pH 9, and water with hydrogen peroxide) was sprayed over the injected H_2S gas with different nozzles (hollow and full cone nozzles) at different operating pressures (70, 140 and 200 kPa).
  - By measuring the H_2S in the exhausted air, the optimum water/nozzle/flowrate combinations to reduce the maximum H_2S were determined.

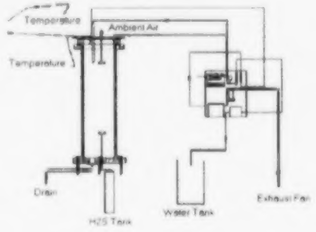

Figure 1. Schematic of setup for H_2S water sprinkling laboratory study.

- Further studies will be made using the top three optimum treatment combinations to reduce H_2S from liquid swine manure. Manure from grower-finisher pigs will be transferred into sixteen 45-gal (use SI units (L) for volume) barrels. The manure will be agitated and the optimal spraying treatment will be applied to evaluate its effectiveness at reducing H_2S emissions.

- *Project 3 – Manure scraper system:*
  - A commercial manure scraper system will be installed in a grower-finisher room.
  - A false floor will be built to raise the channel floor by 0.3 m over the whole length of the channel, and the scraper system will be modified to operate on top of the false flooring. This design will allow for liquids to continuously drain towards the pit plug area.
  - The room air quality and H_2S concentration at the plug area will be compared to an identical room with conventional plugs over three production cycles.
  - Both rooms will house 72 pigs of 25 kg at the beginning of the cycle. Three one-week periods will be monitored over each production cycle: weeks 4, 8 and 12.
  - The temperature, relative humidity, ventilation rate, ammonia and carbon dioxide concentrations in both rooms will be measured on a continuous basis during the monitored week and the H_2S concentration pattern will be monitored during the plug pulling.

Results

- *Project 1 – Remote plug pulling system:*
  - Ten pulling events have been recorded to date, and the maximum H_2S concentration in the room from all the monitored events was 68 ppm. For all pulling events, the H_2S concentration in the alleyway by the winch was 0 ppm.

- *Project 2 – Water-based Sprinkling:*
  - The optimum combination was the hollow cone nozzle, at 200 kPa using water with a pH of 9, resulting in a 79% reduction as in Figure 2.

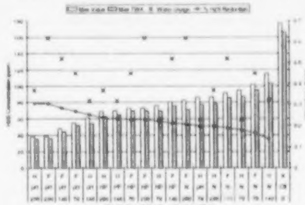

Figure 2. Summary of results for water sprinkling laboratory study.

  - The manure barrel aspect is currently being tested with the hollow cone nozzle at 70, 140 and 200 kPa with water with pH 9.

- *Project 3 – Manure scraper system:*
  - The manure scraper is currently installed and will be studied in 2004.

Conclusions

- The remote plug pulling system allows the worker to pull the manure plug from outside the room. To date, the design works well and effectively reduces the worker's exposure to H_2S.
- The water-based sprinkling system has shown to reduce the maximum levels of H_2S by up to 79%, depending on the nozzle type, water characteristics and operating pressures.

Acknowledgements

Strategic program funding provided by Sask Pork, Alberta Pork, Manitoba Pork and Saskatchewan Agriculture and Food Development Fund.
Project funding provided by SaskPork, PIC and ADF.

Engineering Controls to Reduce Hydrogen Sulphide Exposure in Swine Housing

S.K. Christianson, S.P. Lemay and C. Laguë

Summary

Three hydrogen sulphide (H_2S) control systems that can be retrofitted into existing barns under liquid manure management are investigated. A system that pulls the manure plugs from outside the swine room is effective at reducing worker exposure to H_2S, as is spraying a water-based solution over the H_2S gas. A manure scraper is currently being tested.

Introduction

Previous studies have shown that a serious hazard in swine buildings is the H_2S gas released from the manure. Hydrogen sulphide forms in the manure pit by anaerobic degradation, and if the manure is not agitated most of the H_2S produced remains dissolved in the liquid manure. When barn workers perform manure-handling tasks, such as pulling manure pit plugs, the workers can be at a high risk for exposure to H_2S that is released from the agitated manure.

The goal for this project is to develop and study control methods that may be implemented in current swine barns to reduce H_2S levels during manure handling practices. Three control methods are investigated, including 1) a remote plug pulling system; 2) water-based spraying in the manure pits; and 3) use of a manure scraper.

Experimental Procedures

The remote plug pulling system consists of a winch in the alleyway outside a grower-finisher room that pulls a cable connected to the manure plug, allowing the worker to pull the plug from outside the room. The H_2S levels are measured inside the room when the plug is pulled. The water-based spraying investigates use of different water solutions, system operating pressures and nozzles to reduce levels of H_2S gas. The maximum H_2S concentrations as well as the time-weighted average (TWA) over each minute were compared, and the percent reduction in H_2S was calculated. The top three optimum spraying combinations are then used to determine reduction of H_2S from agitated manure and is currently being completed. The manure scraper will be installed in a grower/finisher room and the room H_2S levels will be measured when scraping occurs over three production cycles. The H_2S levels will be compared with the H_2S from a control room with no manure scraper when the plugs are pulled.

Results and Discussion

To date, the remote plug pulling design works well and effectively reduces the worker's exposure to H_2S. The water-based sprinkling system has shown to reduce the maximum levels of H_2S by up to 79%, depending on the nozzle type, water characteristics and flowrates. The optimum sprinkling combinations are being tested on agitated manure. The manure scraper aspect will be studied in 2004.

Implications

Effective engineering controls to reduce H_2S levels from agitated manure will help protect both swine barn workers and pigs by preventing any health effects due to H_2S exposure.

Acknowledgements

Strategic funding for this project was provided by SaskPork, Alberta Pork, Manitoba Pork and Saskatchewan Agriculture and Food Development Fund. Project funding was provided by SaskPork, PIC and ADF.

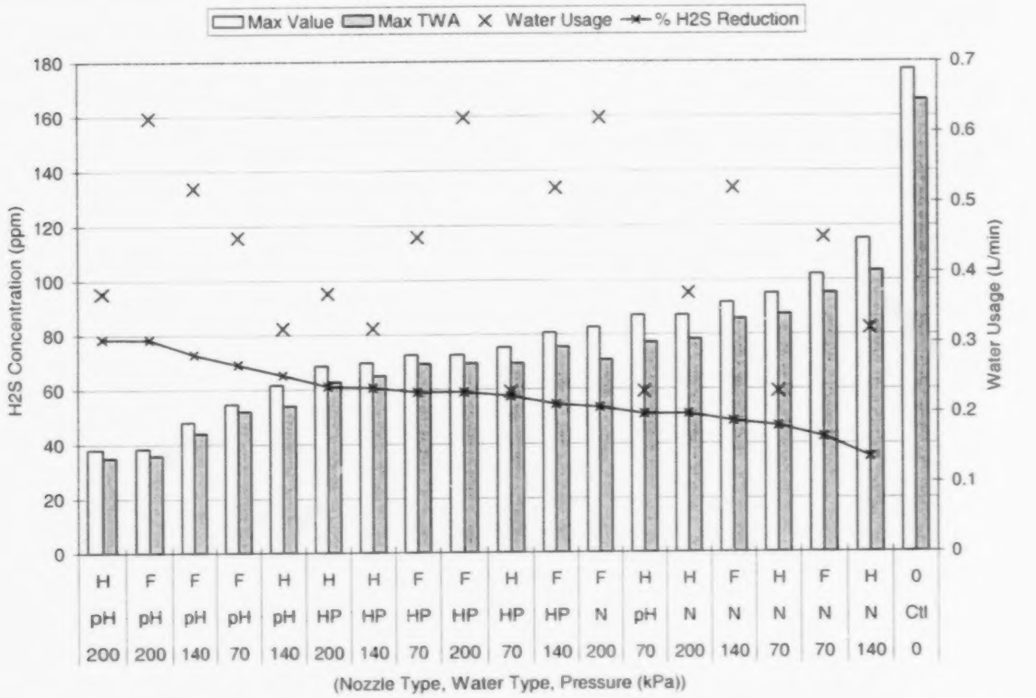

Figure 1. Summary of results for water sprinkling laboratory study (Nozzle Type: H = hollow cone nozzle; F = full cone nozzle; Water Type: pH = water with a pH of 9; HP = water with hydrogen peroxide added; N = normal tap water; Ctl = control test with no spraying).

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Engineering Controls to Reduce Hydrogen Sulphide Exposure of Workers in Swine Buildings

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Abstract. *Two engineering controls were developed to protect swine barn workers from exposure to hydrogen sulphide (H_2S) gas during manure handling operations. A remote manure pit plug pulling system was successfully developed, and testing in two grower-finisher swine rooms showed that the remote pulling system reduced worker exposure to H_2S by allowing the worker to pull the manure pit plug from outside the room. A water sprinkling apparatus was also devised, which, under optimal*

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operating conditions in a laboratory setting, resulted in a 79% reduction of H_2S gas concentration in the air above the water sprinkling system. However, the use of a similar system to reduce H_2S concentration in the airspace above the manure surface when manure was agitated in a 170-L barrel had the opposite effect. Using a Draeger Pac III monitor in the airspace showed that the H_2S concentration actually increased when the water spraying system was in use. Further investigation revealed that the measurement of H_2S concentrations in the airspace above agitated manure with this particular monitor seemed to yield results that were larger than those obtained with other measurement methods. Additional work needs to be done to ensure proper measuring techniques are in place to determine the levels of H_2S that are present from agitated manure.

Keywords. H_2S, plug pulling, water sprinkling, pig manure.

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Introduction

Background

Hydrogen sulphide is a life threatening gas produced by the anaerobic degradation of liquid manure. Most of the H_2S produced by anaerobic bacteria in manure pits remains dissolved in the liquid manure as long as the manure is not agitated. The molecular weight of H_2S (34.08 kg/kmol) is greater than that of air (28.96 kg/kmol), which means that H_2S emitted from the surface of liquid manure in a pit will tend to stratify at the surface of the manure, and considerably slows down the upward diffusion of H_2S in the air.

Results from a research project performed by the PSCI strongly suggest that workers are at risk of H_2S exposure while performing manure management tasks in the barn, such as pulling pit plugs (Chénard et al., 2003). Out of 138 plug pulling events monitored in different barn sections, 114 events (83%) generated H_2S concentrations higher than 15 ppm (Short Term Exposure Limit (STEL) value: time weighted average not to be exceeded for a 15 min exposure period, Saskatchewan Labour 1996) at the worker level above the pits. Monitoring performed along manure pits during emptying also showed that the highest H_2S concentrations obtained were not always measured in the vicinity of the plug but could occur anywhere above the manure channel in the room.

An increasing number of workers on specialized pig operations now spend more time inside the barns on a continuous basis. In some cases workers may be assigned to specific tasks related to manure management that can significantly increase their exposure to H_2S (e.g. manure application contractors, workers assigned to manure management and maintenance of equipment in the barns, crews assigned to power washing and pulling manure pit plugs). Economical and practical preventative measures need to be implemented to help ensure that the H_2S levels do not reach hazardous concentrations in swine barns in order to protect the health and safety of both workers and swine. These measures will assist the swine industry in being both responsible and proactive, and will contribute toward its sustainability and expansion.

Factors Influencing the Release of H_2S

Different factors will either promote or reduce the formation and release of H_2S from swine manure. In an aqueous solution, H_2S gas will ionize to produce H^+ and HS^- (Arogo et al., 2000). Haimour and Sandall (1984) investigated the molecular diffusivity of H_2S in pure water at different temperatures and found that the diffusivity varied from 1.53×10^{-5} cm²/s at 15°C to 2.32×10^{-5} cm²/s at 35°C. When dissolved in an aqueous solution, H_2S forms a weak diprotic acid that dissociates into hydrogen ions (H^+), bisulfide (HS^-), and sulfide (S^{2-}) ions (Arogo et al., 1999). The presence of H_2S in different forms is governed by the following equilibrium equations (Chen, 1974):

$$H_2S_{(aq)} \leftrightarrow H_2S_{(g)} \quad (1)$$

$$H_2S_{(aq)} \leftrightarrow H^+ + HS^-;\ K_{a,1} = 10^{-7.1} \text{ at } 25^\circ C \quad (2)$$

$$HS^- \leftrightarrow H^+ + S^{2-};\ K_{a,2} = 10^{-14} \text{ at } 25^\circ C \quad (3)$$

where $K_{a,1}$ and $K_{a,2}$ are the first and second ionization constants and are mainly functions of temperature.

Arogo et al. (2000) also found that maintaining a pH level greater than 7 in the liquid near the surface of the manure pit will reduce H_2S release by mainly keeping it in the ionic forms. When the pH of the solution decreases, an increase of $H_2S_{(aq)}$ occurs, increasing the potential of $H_2S_{(g)}$ release. When the pH < 5, all the sulfides in the solution exist as H_2S. At pH 7, H_2S and HS^- are present in equal amounts. At pH 10, all the sulfides exist as HS^- and at pH 14 there was 50% HS^- and 50% S^{2-} (Arogo et al., 1999).

Clanton et al. (1999) studied the use of various chemicals added to swine manure to reduce H_2S in a laboratory setting, and found that hydrogen peroxide (H_2O_2) was effective in reducing H_2S gases. The hydrogen peroxide oxides the H_2S gas by the following equations:

pH < 8.5: $$H_2O_2 + H_2S \rightarrow S + 2\ H_2O \qquad (4)$$

or with pH > 8.5: $$4\ H_2O_2 + S^{2-} \rightarrow SO_4^{2-} + 4\ H_2O \qquad (5)$$

Additionally, they comment that raising the pH of the manure by reducing the concentration of hydrogen ions converts H_2S to HS^- and/or $S^=$, but raising the pH also allows ammonia to volatize.

Asai (1990) explains the process where aqueous ferric sulfate ($Fe_2(SO_4)_3$) was used as an absorbent and oxidizes H_2S to elemental sulfur and $Fe_2(SO_4)_3$ was reduced to $FeSO_4$. The reaction was as follows:

$$H_2S + Fe_2(SO_4)_3 \rightarrow S + 2\ FeSO_4 + H_2SO_4 \qquad (6)$$

Objectives

The main goal for this project was to develop and evaluate systems that can prevent or reduce worker exposure to high H_2S concentration during manure handling in swine buildings. The specific objectives were:

Module 1

To design and evaluate an improved pit plug concept that will allow for pit plugs to be opened from a remote location and that will also ensure that the plugs do not pop up due to pressure buildup in sewer lines.

Module 2

To measure H_2S abatement when a water-based liquid is sprayed both in laboratory conditions with H_2S gas and over swine manure when the manure is agitated (mimicking pit plug pulling events).

Module 1 - Improved Design for Pit Plugs

Objectives

The specific objectives of this module included the design and development of a pit-plug pulling system that can:

- Allow the plugs to be opened from a remote location;
- Not allow back-flow of manure or gases when the plugs are closed;
- Be adaptable to as many existing in-barn manure management systems as possible.

Methodology

Two former undergraduate students in Agricultural and Bioresource Engineering at U. of S. (Mr. Bjarnason and Mr. Marshall) selected the topic of designing an improved pit plug for swine manure pits as their Design Capstone project, working under the supervision of Dr. Laguë.

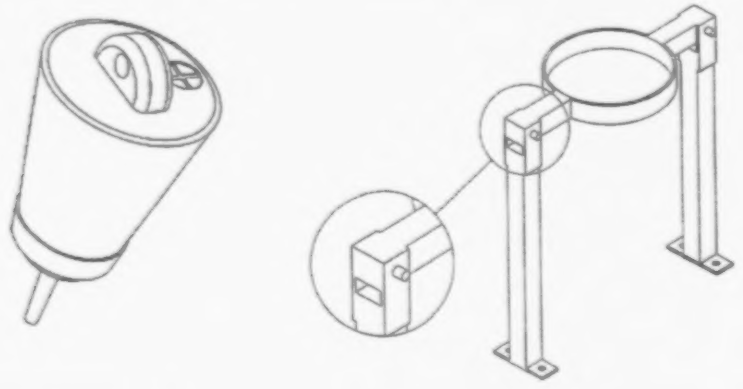
With the assistance of technical staff at U. of S. and PSCI, the students built a bench-scale prototype of their system. This prototype consisted of a large tank (to simulate the hydraulic head at a plug location) with a drain hole at the bottom of the same diameter than that of sewer holes in typical manure pits. Provisions for applying back-pressure, using pressurized air, under the plug were incorporated in the design of the test bench. A testing program aimed at evaluating the performances of the improved plug design in terms of sealing characteristics, ease of opening and closing the sewer hole and resistance to back pressure from the sewer line was completed.

Upon completion of the testing program, the optimum system was selected and built in two grower-finisher rooms at PSCI. The system was then tested in each room by measuring the H_2S concentration using a H_2S monitor (Draeger Pac III monitor equipped with a Draeger H_2S sensor XS EC 1000 ppm, Draeger, Lübeck, Germany; reproducibility of 5%) suspended 1.5 m above the plug area when the plugs were pulled. A similar Pac III monitor was also used in the hallway to measure the H_2S concentration by the plug-pulling winch.

Results

Prototype Design

Several plug designs were examined, including a balloon plug, sphere plug, extended cone plug and inverted plug. The selected solution, the extended cone plug, met the design criteria of low cost, ease of installation, safety, plug popping control and formation of a consistent seal. This design also minimized the flow restriction to the hole. A plug height stop was also designed to prevent the plug from coming out of the hole too far (Fig. 1). With this plug height stop in place, if the plug is pulled or if it pops due to a build-up of pressure, the funnel-shaped extension on the plug will remain in the hole and guide the plug back into the hole and reform the seal.



a) Extended cone plug b) Plug height stop

Figure 1. Schematic diagram of the selected design for the plug and its plug height stop.

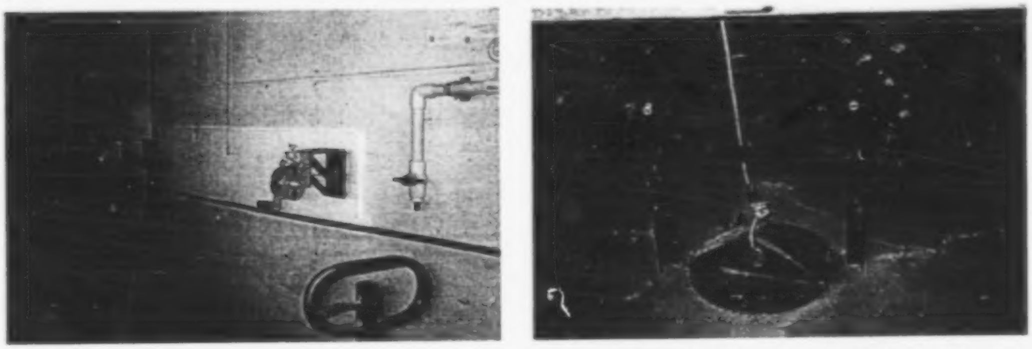
The initial cost, operating cost and maintenance of the plug pulling system were the criteria used to choose among an air pressure system, electric motor apparatus and pulley system. The pulley system with optional winch was selected as the preferred method of mechanical plug pulling.

A prototype of the design was tested in a 204 L barrel that simulated 0.762 m of water head. The force required to pull the plug at four different water heads was measured and, using the developed linear regression equation, the force required to pull the 10.55 kg plug at a maximum manure depth of 1.22 m was estimated to be 630 N. The occurrence of plug popping events was tested by introducing compressed air into a pipe below the plug. Air introduced into the tube leaked around the plug, preventing pressure build-up and plug popping. From the testing and design considerations, it was felt that if the plug did pop due to pressure build-up, the plug height stop and extended cone design would immediately guide the plug back into the hole and reform the seal.

The design and testing stages were completed in December 2002. The design incorporated existing sewer lines and drainage holes in the floor of the pits, helping minimize the initial implementation costs. The pulling mechanism design allowed the two plugs in each pit to be pulled separately, allowing the worker to control which end of the manure pit is emptied.

System Testing

A prototype of the plug system was installed in two full-scale grower-finisher rooms at PSCI in the spring of 2003, and its operation was tested. A plug height stop was also designed to prevent the plug from coming too far out of the hole (Fig. 2).



a) Winches for the system. b) Plug height stop installed in the pit.

Figure 2. Pit plug pulling winch system in the alleyway and the apparatus installed in the pit. There are two winches operating two separate systems, in two different rooms.

In order to pull the plug out using the winch, a cable was threaded around the winch, through a small hole in the wall and through a pulley, which was installed on the wall directly opposite the winch inside the room. Two different cables ran from the room wall up to the plugs with properly set pulleys and anchors (one cable for each plug). Before turning the winch, the cable would be hooked up to the corresponding plug cable and the winch would then be cranked, pulling the plug out of the hole.

Nine pulling events were recorded, with the H_2S concentration measured in both the room where the plug was pulled, and in the alleyway where the winch was located. The maximum H_2S concentration from all the monitored events was 68 ppm, with corresponding concentrations in the alleyway near the winch at 0 ppm. This indicates the system has proven to be very effective in protecting the worker from being exposed to H_2S by allowing the plug to be pulled from outside the room, thus moving the worker outside the danger area.

The cost of building and implementing the system was calculated. The unit cost per pit was 102 CAN$ with the majority of this cost being for the pulling system. The optional winch would cost an additional 40 CAN$, but it could be used for multiple rooms. The cost to implement this design in a 4-plug room was estimated to be 240 CAN$ (280 CAN$ with the winch).

Module 2 – Part 1: Hydrogen Sulfide Abatement by Water-Based Liquid Spraying in Laboratory Conditions

Objectives

A laboratory study was initiated to investigate the potential of sprinkling tap water as an option to reduce H_2S levels from a bench-scale apparatus. The specific objectives were: 1) to examine the impacts of essential oils, of an increase in pH, of ferric sulfate and of hydrogen peroxide added to the sprinkled water to reduce H_2S levels and 2) to determine optimum rates and frequencies for water sprinkling to reduce H_2S levels.

Methodology

Material

Figures 3 and 4 depict the laboratory setup for the H_2S sprinkling system. A PVC pipe 0.9 m high with a 0.3 m diameter was used. A metal ring with predrilled holes was screwed to the top of the pipe, and a solid ring of rubber was laid across the rim with a sheet of plexiglass placed on top. The plexiglass was then siliconed and bolted to the rim of the PVC pipe to create an airtight seal.

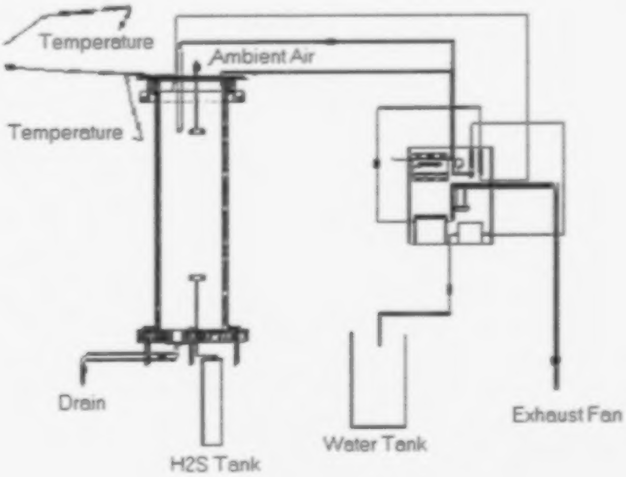


Figure 3. Overall schematic of hydrogen sulphide laboratory setup.

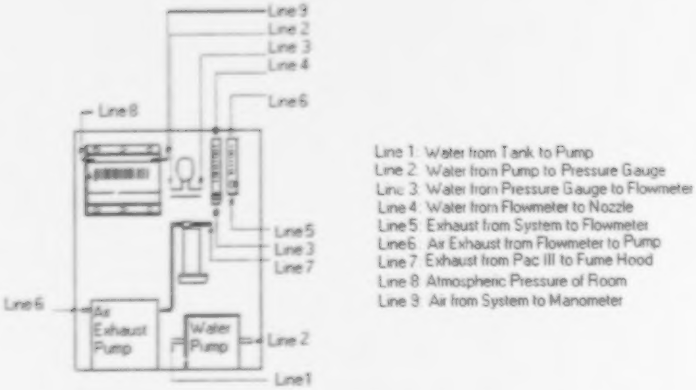

Line 9
Line 2
Line 3
Line 4
Line 6
Line 8
Line 5
Line 3
Line 7
Line 6
Air Exhaust Pump
Water Pump
Line 2
Line 1
Line 1: Water from Tank to Pump
Line 2: Water from Pump to Pressure Gauge
Line 3: Water from Pressure Gauge to Flowmeter
Line 4: Water from Flowmeter to Nozzle
Line 5: Exhaust from System to Flowmeter
Line 6: Air Exhaust from Flowmeter to Pump
Line 7: Exhaust from Pac III to Fume Hood
Line 8: Atmospheric Pressure of Room
Line 9: Air from System to Manometer

Figure 4. Diagram of hydrogen sulphide laboratory system operation.

The measuring devices, including the pressure gauge, rotameters, Pac III monitor, manometer, as well as the pumps were all mounted on a sheet of plywood to ensure easy access to all measurements and equipment during each trial (Fig. 4). The entire setup was placed under the fume-hood in the laboratory and the fume-hood fan was turned on prior to each testing event.

A 550 L tank of 1000 ppm H_2S gas (Praxair, Saskatoon, SK) was used to supply gas into the system. A regulator and rotameter (FM1000 Rotameter, Praxair, Saskatoon, SK) controlled the flowrate of the gas into the pipe. A manifold for the H_2S gas was designed that ensured an even pressure drop of gas into the system, allowing for an even distribution of the H_2S gas inside the pipe at 0.3 m from the bottom of the pipe. The manifold design also ensured that water did not enter the gas inlet lines at the bottom of the tank.

The head space of the tank was ventilated using an exhaust pump (Single head Dia-Vac, Air Dimensions Inc., Deerfield Beach, FL, USA) connected to the exhaust outlet at the top of the pipe to draw air from the system and a flowmeter with a needle valve (Praxair, FM1000, Saskatoon, SK) at the exhaust port monitored the pump flow rate. The air inlet had a similar manifold to the H_2S gas inlet to ensure an even distribution of the inlet air into the pipe. By injecting a known amount of H_2S in the tank, it was possible to recreate an H_2S concentration pattern at the tank air exhaust similar to what was observed in barn conditions during the Chénard et al. (2003) study. The same H_2S monitor as previously described (Pac III monitor equipped with a XS EC 1000 ppm sensor, Dräger, Lübeck, Germany; reproducibility of 5%) was used to measure the H_2S concentration in the exhaust airflow. The calibration connections used for the Pac III were utilized in this system to enable the Pac III monitor to read the H_2S in the exhaust air. The tubing from the exhaust air was then run outside the laboratory. The Pac III monitor was downloaded after each use to observe the patterns of gas emitted from the system.

A 19-L tank was used to supply water to the system and a small diaphragm pump (Bypass Diaphragm Pump, Labcor, Anjou, QC) was used to draw water from the tank and into the pipe. Use of the tank allowed products to be added to the water to test the effect of different liquids on reducing H_2S, including buffer solutions to change the pH and adding hydrogen peroxide to the water.

The system was designed to interchange the nozzle to be tested. Initially, two different nozzles were selected, one which distributed a hollow-cone spray (1/8 A-0.5 WhirlJet Series Spray Nozzle, John Brooks Company Ltd., Winnipeg, MB), and one which distributed a full-cone spray (1/4 T-D1.5-31 UniJet Series Spray Nozzle, John Brooks Company Ltd., Winnipeg, MB). The hollow cone spray nozzle distributed fine water droplets at 0.19 to 0.42 L/min (from 70 to 400 kPa) and the full cone nozzle distributed larger droplets at 0.38 to 0.87 L/min (from 70 to 400 kPa) for one nozzle. Different nozzle flow rates were investigated using a flowmeter with a needle valve (Muis Controls, Rotameter, FR2000 and FR4000 series, Edmonton, AB) and a pressure gauge (2.5" Industrial Gauge, Labcor, Anjou, QC) to change the nozzle operating pressure. After preliminary analysis, a third nozzle with an higher flow rate was selected (full cone nozzle, D6.5, 0.094" TG Unijet Full Cone Nozzle, John Brooks Co., Winnipeg, MB.) Table 1 presents a summary of the nozzles used in this study, along with their operating pressures and flow rate per m^2 of surface area (L/min-m^2) that the water is sprinkled over.

Table 1. Summary of nozzles used for the current study.

Pressure*	**Flowrate (L/min-m^2)****		
(kPa)	**Nozzle 1**	**Nozzle 2**	**Nozzle 3**
35	-	-	25.2
70	2.7	5.4	28.2
100	2.8	5.6	30.6
140	2.8	5.7	33.0
170	2.9	5.9	35.4
200	3.0	6.1	40.2

*Values in kPa were rounded up or down to their nearest factor of 5;
**Nozzle 1 = hollow cone (0.19 to 0.42 L/min from 70 to 400 kPa); Nozzle 2 = full cone (0.38 to 0.87 L/min from 70 to 400 kPa); Nozzle 3 = full cone (1.78 to 5.68 L/min from 35 to 400 kPa)

Experimental approach

The water based sprinkling technique was tested over three trial series. Preliminary work was done to investigate the effect of sprinkling water on reducing H_2S levels using different combinations of nozzles, operating water pressures and water treatments. Exploratory trials were completed to assess the impact of water temperature, the use of ferric sulphate, hydrogen peroxide and the water pH on H_2S reduction. The various treatment combinations were not systematically repeated.

Based on the results from the exploratory trials, an experiment was designed using the most promising treatments to determine the effectiveness of water sprinkling to reduce H_2S gas. The tests included three nozzles with different water treatments (normal tap water, water with hydrogen peroxide added, water with a pH 9, and no water added), sprinkled at three operating pressures (70, 140, 200 kPa). The results for water usage were presented in terms of flowrate per m^2 of surface area (L/min-m^2) that the water was sprinkled over, and the results for the H_2S reduction were presented as a percentage reduction. Each treatment combination was replicated three times.

Based on preliminary results using the three different nozzles, three operating pressures, and four water treatments, the final trials were completed. This final study included only the hollow and the initial full cone nozzles, with three operating pressures (70, 140, 200 kPa) and three water treatments (tap water, tap water with an increased pH 9 and tap water with hydrogen peroxide). Three repetitions were made for each treatment.

Calculations were made to determine the approximate length of time it would take for the PVC pipe to reach various concentrations over various H_2S injection rates. These calculations dictated the size of the PVC pipe and the 1000 ppm inlet H_2S concentration to use for the trials.

Initial studies were performed where the system was filled with H_2S to determine the length of time it takes to reach various concentrations (~200, ~400 ppm) inside the PVC pipe at various inlet flow rates. Adding the H_2S gas at 1000 ppm to the apparatus tank at 1.5 L/min for 2 min created a bell-shape H_2S concentration curve at the exhaust of the tank reaching an average maximum concentration of 177 ppm. This air exchange rate and H_2S injection time was used for all the trials and was defined as the H_2S control concentration curve (Fig. 7). This control concentration curve was considered as being representative of the typical H_2S concentration measured in swine buildings in the Chénard et al. (2003) study.

Data Collection

The H_2S in the exhaust air was continuously monitored at 10 s intervals during each trial. The Pac III monitor was downloaded regularly during each testing period. Immediately prior and upon completion of both the preliminary and final trials, the Pac III monitor was calibrated using standard certified gases (0 and 98 ppm H_2S; Praxair, Winnipeg Canada), and each time the monitors showed little drift (<2 ppm), and resetting of the monitors was not required.

The flow rate and the sprinkling time were used to calculate the water usage. Immediately before the H_2S gas was added to the tank in each study, the water would be turned on and allowed to reach the desired pressure, and was then left to run for 4 min, during which time the H_2S was injected into the tank. The water was drained from the bottom of the tank after each trial, which flowed to an enclosed water tank.

Temperature measurements (type T thermocouple, ±0.5°C) inside the tank, inside the laboratory and inside the water-sprinkling tank were measured and recorded on a datalogger. A manometer was connected to the PVC pipe with one end open to the room to monitor the pressure across the system. All tubes and wiring entering the setup were sealed at their entry points to the system to ensure no H_2S escaped into the laboratory.

System verification and safety protocols

The system was initially tested for any leaks prior to the experiment. The system was placed under pressure and a mixture of soap and water was sprayed on all joints to observe any bubbling, which indicated leakage. After ensuring that all the joints were well sealed, H_2S was injected into the system at a low rate to further ensure that no leakage occured by using H_2S monitors placed near the system. The fan in the fumehood was also checked to verify that adequate pressure difference exists across the fan to draw air out from the fumehood.

When performing the trials all personnel wore a personal Draeger microPac H_2S monitor (Draeger, Lübeck, Germany), and various microPac monitors were placed around the worksite to make sure the workers were at no time exposed to the H_2S gas. If the alarms on the monitors went off at 15 ppm, the workers were to immediately shut off the H_2S tank and exit the laboratory until the alarm subsided. The exhaust fan in the fumehood was continuously running, so any H_2S gas would eventually be exhausted outside. Signs were posted on the laboratory door when the experiment was running to ensure those entering the lab were aware of the work being done in the lab and to advise people to evacuate the lab immediately if the H_2S monitor alarms went off.

Data Analysis

All the treatment combinations tested were compared to the control H_2S concentration curve, where no liquid was added to the system. Both the maximum and the time weighted average (TWA) of the H_2S concentration for each treatment combination was compared to the maximum and the TWA of the control H_2S curve. The TWA was taken over four minutes, with the average for each 60 s.

The following equation was used to calculate the difference between the H_2S control curve and treatments:

$$Reduction_{H2S} = \left(\frac{(C_{Control-Max} - C_{Treatment-Max})}{C_{Control-Max}} \right) * 100 \qquad (7)$$

Where: $Reduction_{H2S}$ = Reduction of the H_2S concentration (%);

$C_{Control-Max}$ = Maximum H_2S concentration measured at the tank exhaust over the 6-min test without any water sprinkling (ppm);

$C_{Treatment-Max}$ = Maximum H_2S concentration measured at the tank exhaust over the 6-min test with the specific water sprinkling treatment (ppm).

The optimum treatment combinations were selected based on the preliminary results, and a controlled study was completed using a randomized complete block design for the final trials. Equation 7 was used in a similar manner to calculate the impact of treatments on the TWA values.

Results

Exploratory trials

After preliminary testing was done on the nozzles, it became apparent that when normal tap water was used, a nozzle with a higher flow rate would reduce the levels of H_2S gas more than a nozzle with a lower flow rate. Figure 7 illustrates that the largest reduction in H_2S was obtained with the full cone nozzle used at 240 kPa (0.6 L/min; 35% reduction), as compared to the hollow cone nozzle at both 100 kPa (0.3 L/min; 18% reduction) and 240 kPa (0.4 L/min; 19% reduction).

The effect of the sprinkled water temperature on the reduction of H_2S was also studied. A 23% reduction in the maximum H_2S concentration was measured with the cooler water (15°C) versus the warmer water (25°C). These results were consistent with results obtained by Haimour and Sandall (1984), who also found that a reduction in water temperature decreased the diffusivity of H_2S in pure water. It is expected that a further reduction in temperature would further reduce the H_2S concentration. For purposes of this study the testing was done using water at 17°C.

Studies with ferric sulfate revealed that the addition of the chemical to the incoming sprinkled water dropped the pH of the sprinkled water between 2 and 3. As well, when the water with ferric sulfate was sprinkled, the H_2S concentration in the exhaust air reached 159 ppm, a 29% higher concentration than when the system was sprinkled with normal water (113 ppm) for the same nozzle and water pressure. Moreover, it was difficult to maintain the desired pressure of the system as the ferric sulfate did not dissolve well in the water and the ferric sulfate granules tended to block the nozzles. Based on these results, it was decided to not investigate the use of ferric sulfate further in this experiment.

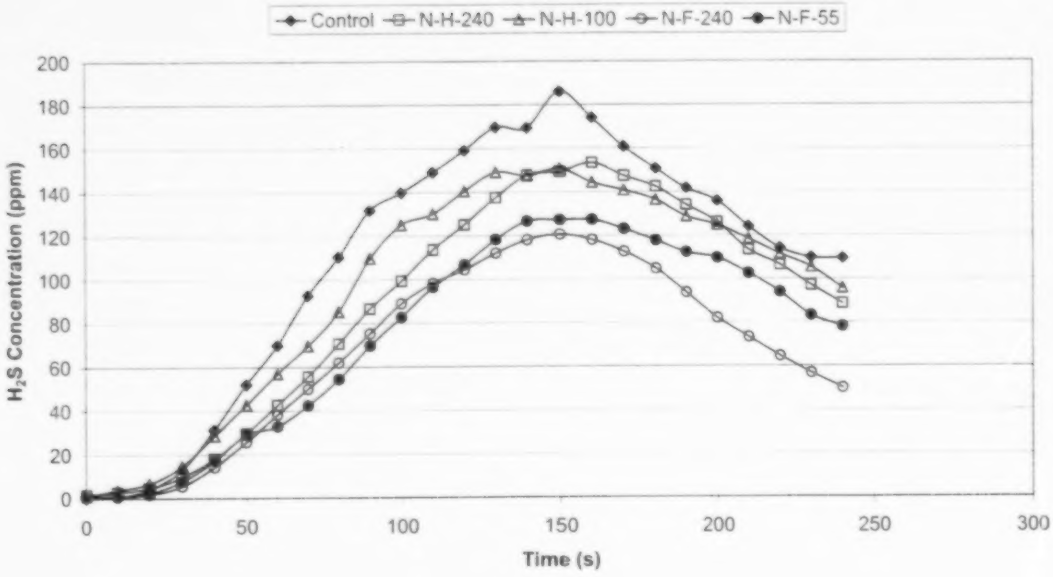


Figure 7. Summary of H_2S measurements with an H_2S injection rate of 1.5 L/min for 2 min (Control, spraying of tap water with hollow cone nozzle at 240 (N-H-240) and 100 kPa (N-H-100); or with full cone nozzle at 240 (N-F-240) and 55 kPa (N-F-55)).

Further testing showed that increasing the pH of the sprinkled water to 9 has potential to reduce the concentration of H_2S in the exhaust more so than sprinkling normal tap water. Additionally, it has been found that a much smaller volume of water would be needed if the pH of the water was increased to 9, which will have the advantage of decreasing the volume of water to be used and stored in the manure pit. In addition, sprinkling water with hydrogen peroxide added reduced the H_2S to 70 ppm, a 61% reduction.

Preliminary trials

Figure 8 is a summary of the results from using the three nozzles with different water treatments (normal tap water, water with hydrogen peroxide added, water with a pH 9, and no water added), sprinkled at different operating pressures.

From Fig. 8., it is evident that the full cone nozzle with a higher flow rate, used with water at pH 9 and sprinkled at 170 kPa reduced the concentration of H_2S the greatest (79%), but the water usage (35.4 L/min-m^2) was much higher than the full cone nozzle with a lower flow rate, pH 9 at 100 kPa (5.8 L/min-m^2), which saw an H_2S reduction of 67%. Calculations show that if the hollow cone nozzle was used in a grower-finisher swine manure pit to sprinkle water over the entire pit for 15 min while the pit was draining, the total volume of water used (1.0 to 1.6 m^3) would be in the range of 5% to 8% of the total manure pit volume. If the full cone nozzle with the higher capacity was used at 170 kPa, the total volume of water used over 15 min would be 11.1 m^3, or 57% of the total manure pit volume. Based on these results, it was concluded that the final trials would use only the initial hollow cone nozzle and full cone nozzle with a lower flow rate, and the full cone nozzle with a higher flow rate would no longer be investigated as it utilized much more water than necessary (84%) for a 12% additional decrease in maximum H_2S concentration. This additional water would ultimately put a higher burden on the volume of water used, and would increase the volume of manure. This additional water would also increase both the volume needed to store the water in the lagoon, and the manure spreading costs.

In addition, it is likely that spraying would not have to be performed over the entire manure pit, and total sprinkling time could be shorter than 15 min, so the addition of water using the hollow cone nozzle corresponding to 5% to 8% is likely a conservative estimate that could be reduced in the final design.

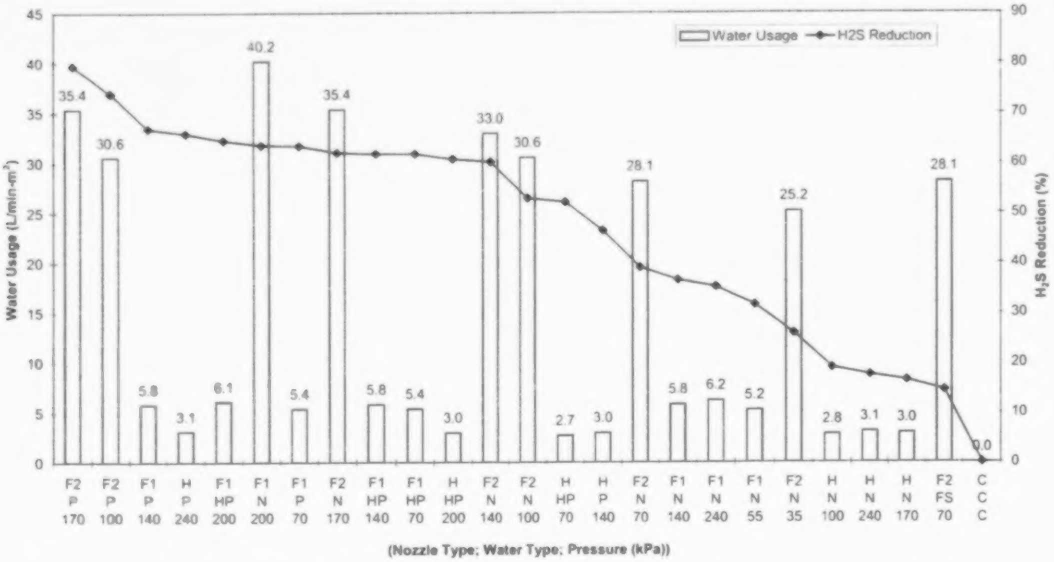


Figure 8. Summary of preliminary trials using three nozzle types (F1; F2 and H – full cone 1, full cone 2 and hollow cone, respectively) using different water treatments (P = pH 9; HP = hydrogen peroxide added to water; N = normal tap water; C = control (no water added)) at various pressures.

Final Trials

Based on preliminary results using the various treatments (three different nozzles, three operating pressures, and four water treatments), the final experiment used only the hollow and the initial full cone nozzles, with three operating pressures (70, 140, 200 kPa) and three water treatments (tap water, tap water with an increased pH 9 and tap water with hydrogen peroxide). Three repetitions were made for each treatment.

The results from this trial are presented on Fig. 9. There were no significant differences between the blocks ($P>0.05$), and there were significant differences among both water type and nozzle type ($P<0.05$). There was also a significant difference between the water*nozzle*pressure interaction ($P<0.05$), which tells us that each treatment was significantly different from the others. The best reduction of H_2S occurred when the hollow cone nozzle was used at 200 kPa using water at a pH of 9, resulting in a 79% reduction of the maximum H_2S. Use of a full cone nozzle at pressures 70, 140 and 200 kPa resulted in high levels of H_2S reduction as well, but the water volume used was much higher than for the hollow cone (18 to 63% more water).

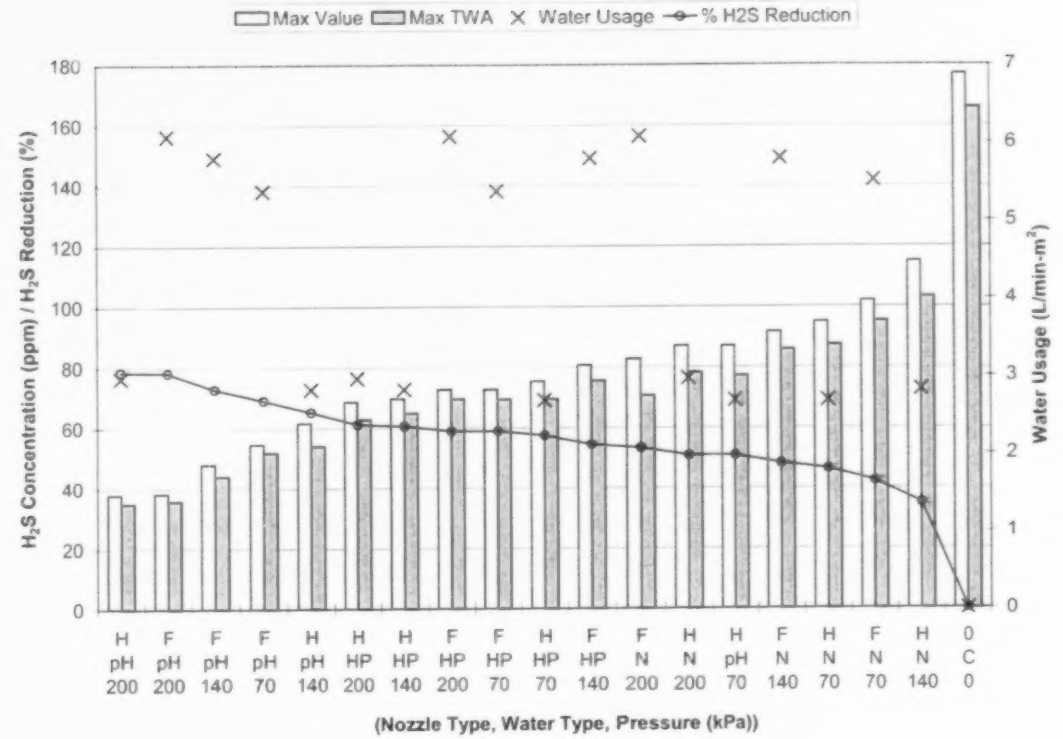


Figure 9. Summary of final trial results (Nozzle Types: H (hollow cone) and F (full cone); Water Type: pH (water at pH 9), HP (water with hydrogen peroxide added), and N (normal water); Pressures: 70, 140 and 200 kPa).

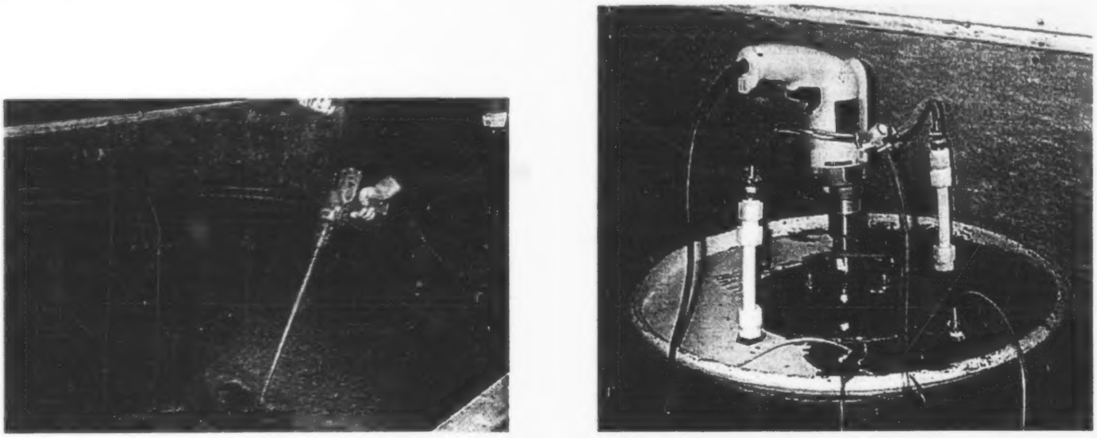
Module 2 – Part 2: Hydrogen Sulfide Abatement by Water-Based Liquid Spraying with pig manure

Objectives

Since the hollow cone nozzle saw a high reduction of H_2S (51 to 79% reduction) with tap water at pH 9 and used much less water than the full cone nozzle, the objective of the subsequent part of the study was to investigate the use of hollow cone nozzles at 70, 140 and 200 kPa with tap water at pH 9 to reduce H_2S from agitated swine manure.

Methodology

Sixteen 170-L barrels were filled with manure from grower-finisher swine by using a sewage pump in the manure pit of a grower-finisher room to pump manure into a large tub. The manure was mixed in the tub using a power drill and paint mixer as in Fig. 10a. After mixing, the manure was scooped into 170-L barrels, with one tub of manure filling four containers two-thirds full. Filling four barrels from one tub of manure allowed grouping of the manure samples in forming one block, as each batch of manure varied slightly in consistency. Each block included one replicate of each treatment, and the whole experiment included four blocks. The barrels were transported to an empty room in the PSCI barn and allowed to sit undisturbed for three days.



a) Manure mixing. b) Manure barrel mixing lid.

Figure 10. Mixing manure sample to be placed in barrels.

A single lid was designed and fabricated with a mixer, nozzles and exhaust and inlet ports as in Fig. 10b. A bearing was welded onto the lid that held a paint mixer in place and allowed the mixer to be rotated using a power drill. Each hole made in the lid was sealed. The same setup as the laboratory study was used to measure the H_2S in the exhaust air from the barrel (Figs. 3 and 4), with the exhaust air from the Pac III monitor exhausted outside through the room fan.

For each measuring event, the lid on the manure barrel was removed and the mixing lid was placed on the barrel. The mixer on the lid would agitate the manure slightly, and the exhaust pump was then turned on, drawing air from the barrel over the Draeger Pac III monitor. The mixer was allowed to remain stationary until the H_2S reading on the Pac III monitor read <10 ppm, which generally took about 15 min. After the H_2S reading read <10 ppm on the Pac III monitor, the power drill was turned on, and to ensure consistent mixing between barrels, a tachometer was used to measure the rotation speed of the mixer. For all treatments and controls, the manure was mixed at 220 RPM for 1.5 min. For the control barrels, no water was sprayed while mixing the manure, and the concentration of H_2S was measured in the exhaust. For the treatment barrels, the water was turned on prior to agitation.

As with the laboratory phase of this study, Equation 7 was used to determine the difference between the control and treatments.

Results

After placing the mixing lid on the barrel of manure and allowing the exhaust concentration of H_2S to reach <10 ppm, four control barrels were agitated and the H_2S concentration measured. An average of 148 ppm was found with the four control barrels, with a maximum of 520 ppm. However, when water at a pH of 9 was added to the system at 100 kPa using the hollow cone nozzle, and the manure was agitated in the same manner as the control, both the average and maximum H_2S concentration measured in the exhaust air of three treatments increased to 273 and 690 ppm, respectively. Figure 11 depicts the measurements taken by the Draeger Pac III monitor for this study. These results were the reverse of what was expected based on the laboratory study, where sprinkling the water reduced the levels of H_2S. Since the laboratory study used pure H_2S gas and the manure study contains numerous other gases in the exhaust air, it was suspected that the other gases had an impact on both the Draeger Pac III monitor and the actual levels of H_2S inside the headspace of the barrel.

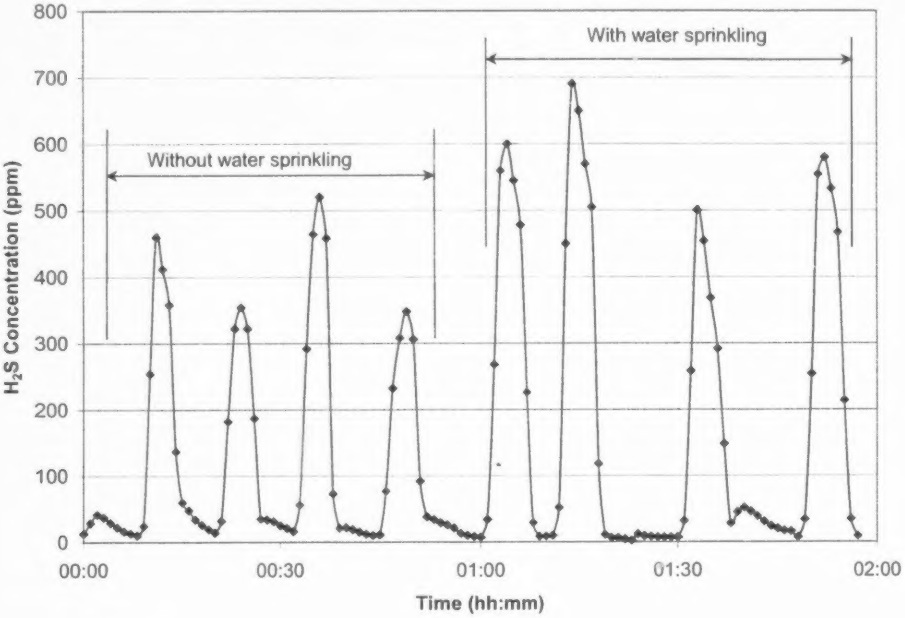


Figure 11. Summary of control and treatment with manure barrels. The first four peaks are the control tests, with no water added. The last four peaks are the treatment, with water with pH 9 sprinkled using a hollow cone nozzle at 100 kPa.

A test was done to determine what happened inside the manure barrel when water was sprinkled and no agitation occurred (Fig. 12). At time 0 the air exhaust pump was turned on. After 3 min, the mixing lid was placed inside one barrel and the concentration of the exhaust air was allowed to reach 24 ppm. When the water at pH 9 was sprinkled inside the barrel for 30 min at 100 kPa, with no manure agitation, sporadic levels of H_2S were recorded over the 30 min, with a maximum of 1000 ppm and an average of 343 ppm, as shown on Fig. 12. It is uncertain why the H_2S levels fluctuated as on Fig. 12 and no reasonable explanation was found to justify the H_2S monitor readings from manure barrels.

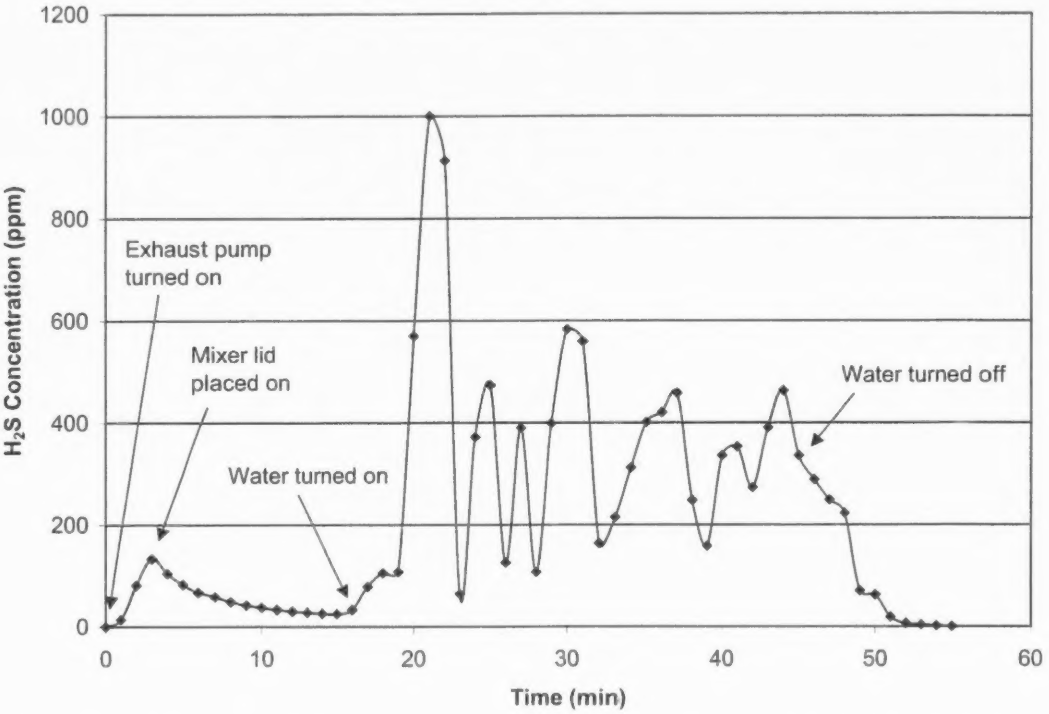


Figure 12. Effect of sprinkling water on manure in barrel with no agitation of the manure.

The Draeger Pac III monitor operating manual includes a list of cross-sensitivities to other gases including ammonia, carbon dioxide, methane, and several other gases. This list is presented in Table 2, and the largest cross sensitivity of a single gas for the Pac III monitor that is listed in the manual is from methanol, which could see a deviation of ≤20 ppm. As mentioned in the manual, there could also be other gases that affect the reading of the Draeger Pac III monitor that are not listed in the operating manual.

Additional testing was performed to compare the readings of the Draeger Pac III monitor with H_2S chemical detector tubes and gas chromatography (GC) using real swine manure. Considering the scope and resources of the current study, it was not possible to complete an exhaustive comparison of the three measuring techniques and only general trends can be discussed.

From the data points available, the measurements were similar between the chemical tubes and the GC, but the Draeger Pac III monitor reading was much higher than the chemical tube and GC measurements. Even thought the Draeger Pac III monitor maintained its calibration using the zero and the span gases, its reading was likely affected by other gases emitted from the manure. Therefore, further work needs to be done to establish the effect of other manure gases on the reading of the Draeger Pac III monitors.

Considering the current level of knowledge, it is strongly recommended to always compare the readings of electronic monitors to other measuring techniques when used with real swine manure even when monitors perform well compared to reference gases.

Table 2. Summary of cross-sensitivities listed in the Draeger Pac III operating manual.

Gas / Dampf	Chemisches Symbol	Testgas-konzentration	Abweichung des Meßwertes in ppm H_2S
Gas / Vapour	Chemical symbol	Test gas concentration	Deviation from measured value in ppm H_2S
Aceton / Acetone	CH_3COCH_3	1 000 ppm	≤ 4
Ammoniak / Ammonia	NH_3	500 ppm	≤ 1
Benzol / Benzene	C_6H_6	0,6 Vol.-%	≤ 1
Carbonylchlorid / Carbonylchloride	$COCl_2$	50 ppm	≤ 1
Chlor / Chlorine	Cl_2	8 ppm	≤ 2 (–)*
Chlorwasserstoff / Hydrogen chloride	HCl	40 ppm	≤ 1
Cyanwasserstoff / Hydrogen cyanide	HCN	50 ppm	≤ 1
Ethanol / Ethanol	C_2H_5OH	200 ppm	≤ 2
Ethanthiol / Ethyl mercaptan	C_2H_5SH	10 ppm	≤ 5
Ethen / Ethene	C_2H_4	1 000 ppm	≤ 10
Ethin / Ethine	C_2H_2	0,6 Vol.-%	≤ 10
FAM-Normalbenzin / FAM petrol (DIN 51635, DIN 51557)	——	0,55 Vol.-%	≤ 1
Hexan / Hexane	C_6H_{14}	0,6 Vol.-%	≤ 1
Kohlendioxid / Carbon dioxide	CO_2	1,5 Vol.-%	≤ 1 (–)*
Kohlendisulfid / Carbon disulphide	CS_2	15 ppm	≤ 1
Kohlenmonoxid / Carbon monoxide	CO	125 ppm	≤ 3
Methan / Methane	CH_4	5 Vol.-%	≤ 1
Methanol / Methanol	CH_3OH	200 ppm	≤ 10
Oktan / Octane	C_8H_{18}	0,4 Vol.-%	≤ 1
Propan / Propane	C_3H_8	1 Vol.-%	≤ 1
Propen / Propene	C_3H_6	0,5 Vol.-%	≤ 1
Phosphorwasserstoff / Phosphine	PH_3	5 ppm	≤ 5
Schwefeldioxid / Sulphur dioxide	SO_2	20 ppm	≤ 4
Stickstoffdioxid / Nitrogen dioxide	NO_2	20 ppm	≤ 1
Stickstoffmonoxid / Nitrogen monoxide	NO	20 ppm	≤ 10
Tetrahydrothiophen / Tetrahydrothiophene	C_4H_8S	10 ppm	≤ 4
Tuol / Toluene	$C_6H_5CH_3$	0,6 Vol.-%	≤ 1
Wasserstoff / Hydrogen	H_2	1 Vol.-%	≤ 10
Xylol / Xylene	$C_6H_4(CH_3)_2$	0,5 Vol.-%	≤ 4

Conclusions

A remote manure plug pulling system was successfully developed. Results show that the worker was exposed to zero concentrations of H_2S in the alleyway close to where the plug was pulled, compared to an exposure of up to 68 ppm inside the room where the plug was pulled. The system was designed in a manner such that if the plug popped out due to back pressure in the sewage lines, the plug would slide back into place when the manure drained from the channel and would not remain open, thus preventing backdraft of H_2S into the room from the sewage lines. The system was also designed for existing manure pits, minimizing the system implementation costs.

A laboratory study was carried out to measure the efficacy of sprinkling water to reduce H_2S gas from the air. Several water treatments were tested, as well as different spraying nozzles and different flowrates. By sprinkling water with a pH 9 at 200 kPa using a hollow cone nozzle, a 79% reduction in H_2S gas was measured.

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Cyanwasserstoff / Hydrogen cyanide	HCN	50 ppm	≤ 1
Ethanol / Ethanol	C_2H_5OH	200 ppm	≤ 2
Ethanthiol / Ethyl mercaptan	C_2H_5SH	10 ppm	≤ 5
Ethen / Ethene	C_2H_4	1 000 ppm	≤ 10
Ethin / Ethine	C_2H_2	0,6 Vol.-%	≤ 10
FAM-Normalbenzin / FAM petrol (DIN 51635, DIN 51557)	——	0,55 Vol.-%	≤ 1
Hexan / Hexane	C_6H_{14}	0,6 Vol.-%	≤ 1
Kohlendioxid / Carbon dioxide	CO_2	1,5 Vol.-%	≤ 1 (–)*
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A laboratory study was carried out to measure the efficacy of sprinkling water to reduce H_2S gas from the air. Several water treatments were tested, as well as different spraying nozzles and different flowrates. By sprinkling water with a pH 9 at 200 kPa using a hollow cone nozzle, a 79% reduction in H_2S gas was measured.

A subsequent study was carried out using agitated manure as the source of H_2S to test the optimum treatment combinations developed in the laboratory study. However, use of the Draeger Pac III monitor to measure the exhaust air from agitated manure generated results that are inexplicable at the present time. When sprinkling water over the manure headspace the H_2S concentration increased, even when the manure was not agitated. This was not expected to happen based on the laboratory study where the sprinkled water reduced the levels of H_2S, as expected based on the literature review.

Additional work was done to explain the readings of the Draeger Pac III monitors with real swine manure and no reasonable explanation is available at this point. However, it is strongly recommended to further investigate H_2S measuring techniques in comparing readings from monitors similar to the Draeger Pac III monitor with other monitoring techniques like gas chromatography even when monitors seem to perform adequately compared to reference gases.

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Evaluation of a Manure Pit Scraper System for Controlling Hydrogen Sulfide Gas in Swine Barns

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Abstract. *A manure pit scraper system was installed in a swine grower-finisher room and used to remove manure daily from the manure pit. Preliminary measurements showed that H_2S levels in the scraper room was lower by an average of 80 to 96% compared to measurements in a similar room operated under normal conditions. However, ammonia emissions in the scraper room were about 44% higher compared to the control grower-finisher room.*

Keywords. Air quality, ammonia, hydrogen sulfide, scraper, swine

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Introduction

Hydrogen sulfide (H_2S) gas in swine barns is produced by the anaerobic degradation of liquid manure. Exposure to H_2S can have detrimental effects on both workers and swine, especially at excessively high levels (CHEMINFO, 2000). Most of the H_2S produced by anaerobic bacteria in manure pits remains dissolved in the liquid manure as long as the manure is not agitated. Results from a research project performed by the Prairie Swine Centre Inc. (PSCI) strongly suggest that workers are at risk of H_2S exposure while performing manure management tasks in the barn, such as pulling manure pit plugs (Chénard et al., 2003). Out of 138 plug pulling events monitored in different barn sections, 114 events (83%) generated H_2S concentrations higher than the short-term exposure limit (STEL) value of 15 ppm (or time-weighted average concentration not to be exceeded during a 15 min exposure period, specified by Saskatchewan Occupational Health and Safety) at the worker level over the pit area. Monitoring performed during emptying of manure pits also showed that the highest H_2S concentrations measured were not necessarily restricted in the vicinity of the plug but may occur elsewhere in the room above the manure channel.

An increasing number of workers in specialized pig operations now spend more time inside the barns on a continuous basis. In some cases workers may be assigned to specific tasks related to manure management that can significantly increase their exposure to H_2S (e.g., crews assigned to power washing and pulling manure pit plugs, or those assigned to operation and maintenance of manure handling equipment in the barns). Economical and practical preventative measures need to be implemented to help ensure that the H_2S levels do not reach hazardous concentrations in swine barns to protect the health and safety of both workers and animals. Modification of the current design of shallow pit in-barn manure handling system to allow for more frequent and complete removal of manure from the production rooms has the potential to reduce H_2S production and emission. Such measures can help ensure productivity of swine operations and contribute to long-term sustainable growth of the swine industry.

Project Objectives

The overall goal of this project was to develop systems that will prevent or reduce worker exposure to high H_2S concentrations during manure handling in swine buildings. Specifically, this study aimed to develop a manure pit scraper system that will remove swine manure from the barn on a daily basis, and evaluate the impact of the system on H_2S concentrations and other air quality parameters in the barn. Ultimately, the goal was to develop a system that can be retrofitted into existing barns with liquid manure handling systems.

Methodology

Grower-finisher room set-up

Two commercial grower-finisher rooms at the PSCI barn were used over two production cycles. Each room had partially slatted floors and was 14.2 m long, 5.4 m wide, with 3.0 m ceiling. Ventilation in each room was provided by three fans that pull air from the attic through six ceiling inlets. A forced air recirculation duct was located on one side of the room near the ceiling, and a 17.6 kW natural gas heater provided supplemental heat. The two rooms contained six pens each and were mirror images of each other. Each pen was 2.0 m wide and 4.2 m long, and had a nipple drinker and a dry feeder connected to an automatic feeding system. For this experiment, one pen remained empty throughout the trial and the other pens had 14 pigs each, for a total of 70 pigs per room. The empty pen was used to gain access to the scraper system to make adjustments as part of a separate experiment.

In one of the rooms (Experimental), the manure scraper system was installed and operated daily, while the other room (Control) was operated normally, i.e., manure was allowed to accumulate in the pits and the pit plugs were pulled on a predetermined schedule. Pigs entered the rooms at about 21.5 kg, remained in the rooms for about 12 weeks, and attain an average weight of about 96.5 kg at the end of the study. The pigs were weighed at the beginning of each trial and sorted to ensure that the difference in the total starting weight for the two rooms was within ±1.0 kg.

Scraper set-up

The manure scraper system was assembled and installed in the manure pit of one of the rooms. The main components of the scraper system were obtained from a commercially-available system manufactured in Québec where such systems are used in some swine operations and in other livestock (dairy) industries (Figs. 1 & 2). The manure channel in the room was 14.2 m long, 1.8 m wide and 0.6 m deep, with a pit drain at each end. To ensure complete drainage of the manure when the scraper was operated, a false floor was laid on the manure channel bottom surface to raise the manure pit floor by 0.25 m at one end, which gradually sloped down to 0.20 m on the other end. The scraper blade ran over the false floor surface (Fig. 1), although it did not cover the entire length of the manure channel; it stopped at about 1.1 m from one drain on one end and about 1.6 m from the drain on the other end, thus leaving an area around the drain where manure accumulated. Two manure tubs were built out of mild steel and one was placed at each end of the false floor. All sides of this tub were sloped toward the pit drain (with a pit plug) at its center, to ensure complete drainage of manure into the drain hole when the plug was pulled and to prevent retention of any manure from which H_2S could be produced (Fig. 3).

The scraper system was operated daily, dropping the solids from the false flooring into the accumulation pit, after which the plug was immediately pulled to let the manure drain as a slurry mixture.

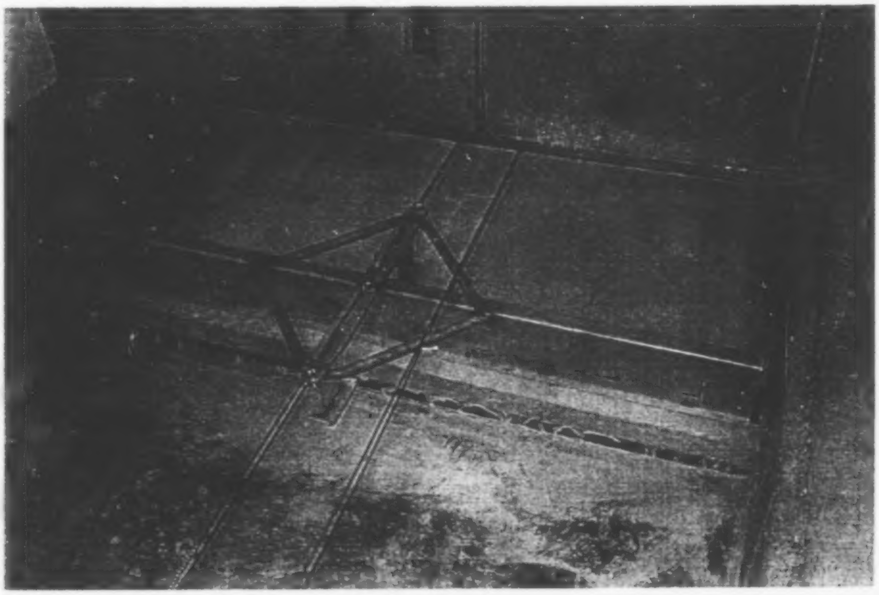
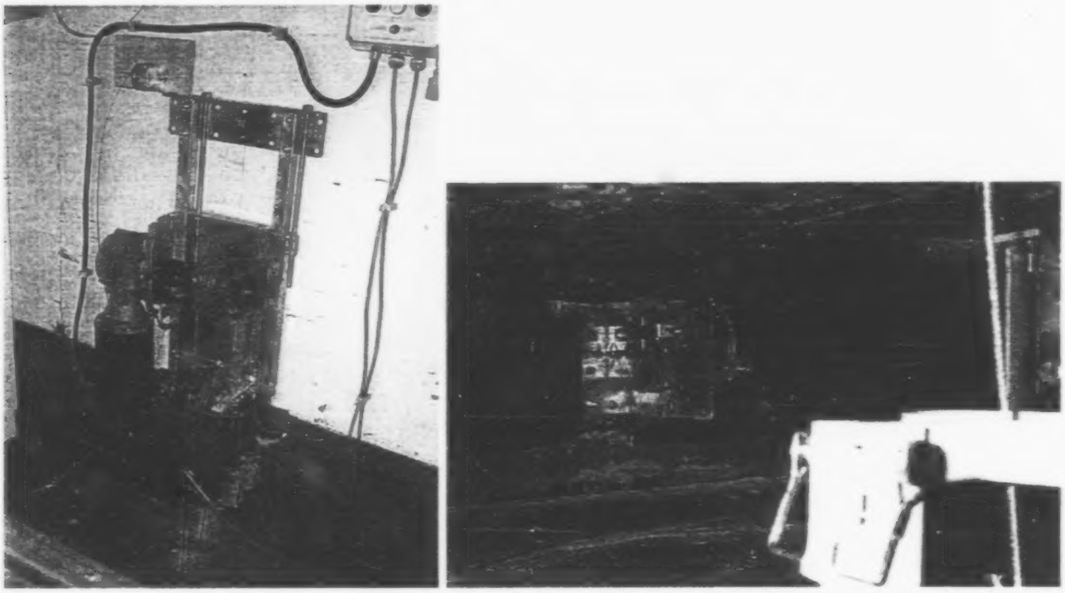


Figure 1. Scraper blade that was pulled over the false flooring. The manure pit has two drains, one at each end, through which the scraped manure was drained to the sewer line.



(a) (b)

Figure 2. Components of the scraper system including the (a) electric motor, controls, and (b) pulley system used to pull the scraper blade in both directions.

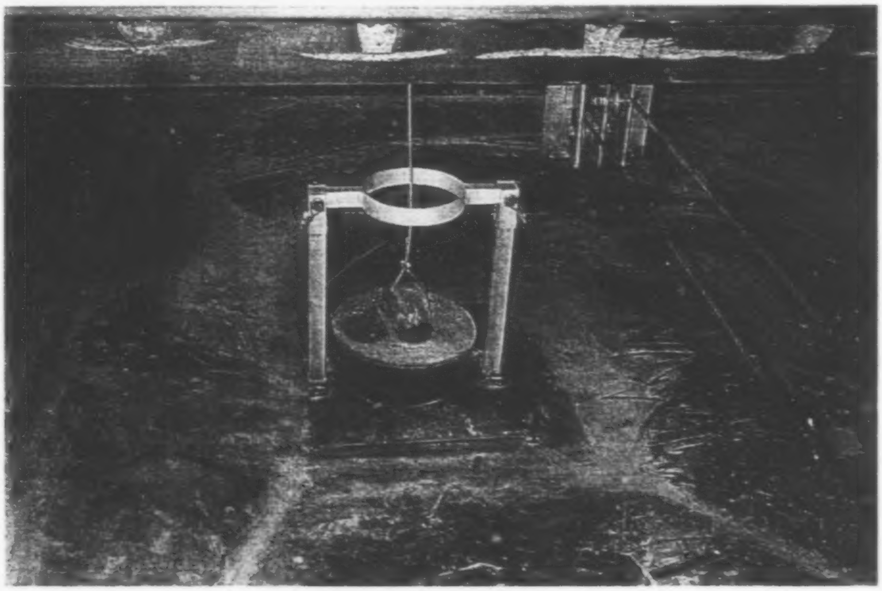


Figure 3. Pit drain with a pit plug located in the middle of the accumulation tub. At each end of the pit, a sloping tub was installed to facilitate clearing the scraped manure into the pit drain.

Data Collection

The room air quality and H_2S concentrations in the experimental (scraper) room were compared to an identical room with conventional plugs (control) over two production cycles. Four one-week periods were monitored over each production cycle: weeks 4, 6, 8 and 10, which comprised one trial. The pit plug in the control room was pulled in the middle of each of the one-week monitored periods. The schedule of monitoring was set to coincide with normal plug pulling schedules in the rooms, which allowed for manure to accumulate initially over a 4-week period while the pigs were small, while subsequent tests were done after every two weeks to account for larger manure production as the pigs grew larger. For each scraping and pulling event during the monitored week, two H_2S monitors (Model Pac III, with XS EC 1000 ppm H_2S sensor, Draeger, Lübeck, Germany; reproducibility of 5%) were installed in each room: one over the middle of the manure pit (middle pen) and another directly above the plug, both at about 1 m off the floor. The monitors, which recorded H_2S readings at 10-sec sampling interval, were turned on five minutes before pulling the plug. Preliminary tests were done to determine the length of time that the pit drains need to remain open for the slurry to drain completely, since leaving the drain open longer than necessary could allow a back draft of H_2S to the room from the sewer line. After the plug was replaced, the monitor remained on for another 5 min to obtain H_2S measurements both before and after the pulling event.

In the experimental room, the scraper system was operated daily and the pit plug was remotely pulled daily as well. The monitors were turned on five minutes before scraping the channel. After scraping was completed, the plug was pulled and the plugs remained open for 10 min. After replacing the plug, the monitor will remain on for another 5 min to obtain H_2S measurements both before and after the pulling event.

The air quality in both rooms was measured on a continuous basis during the monitored week. Ammonia concentrations were measured at the inlet and outlet of both rooms using a sampling manifold system attached to an ammonia analyser (Model Chillgard RT, MSA Canada, Edmonton, AB; accuracy of ±2 ppm). Ammonia readings from each monitored location were taken every 55 min during Trial 1 and every 43 min for Trial 2. Every 10 minutes, temperature and relative humidity were measured in each room, as well as the fan speed and static pressure to calculate the ventilation rate in each room.

Data analysis

The H_2S levels were compared between the two rooms in terms of the maximum daily H_2S concentration and the 15-min time-weighted average (TWA) to determine the percent reduction in H_2S. The ammonia emission levels were compared between the two rooms as well using the following equation:

$$\%\ \text{Reduction} = \frac{\text{Control} - \text{Experimental}}{\text{Control}} \times 100 \qquad (1)$$

The time-weighted average values were calculated by:

$$\text{Time-weighted average, TWA} = \frac{\sum(H_2S\ \text{concentration readings} \times \text{Sampling interval})}{\text{Sampling duration}} \qquad (2)$$

The ammonia emission for each room was calculated using the following equation, with the appropriate conversion of units:

$$\text{Emission rate} = \text{Ventilation rate} \times (\text{Exhaust concentration} - \text{Inlet concentration}) \qquad (3)$$

Preliminary results

Summary of trials

Two trials were completed from March 8 to August 27, 2004, corresponding to two production cycles. Table 1 summarises the weekly average values for temperature and relative humidity in the two rooms. Outdoor ambient conditions during the first three weeks of Trial 1 were cold, thus the ventilation rates in both rooms were lower compared to the rest of the trials. In general, nearly similar conditions were maintained in both rooms throughout the trials, as can be observed from the close mean values for temperature, RH and ventilation rates measured in the two rooms (Table 1).

Table 1. Summary of weekly average values for temperature, relative humidity and ventilation rates measured in the experimental (scraper) and control rooms.

	Monitored week dates	Average room temperature (ºC)		Average relative humidity (%)		Average ventilation rate (L/s)	
		Scraper	Control	Scraper	Control	Scraper	Control
Trial 1	Mar8-12	18.3	18.3	48.5	N/A	768	808
	Mar22-26	16.4	16.3	52.2	51.5	881	859
	Apr5-9	15.5	16.2	43.5	43.8	1661	2111
	Apr19-23	16.1	16.4	37.9	36.6	2310	2382
Trial 2	Jun28-Jul2	23.1	23.9	47.2	49.5	3035	2938
	Jul19-23	22.8	23.4	63.1	63.0	3230	3208
	Aug9-13	19.6	21.8	58.9	59.0	3022	2858
	Aug23-27	17.7	17.3	62.1	63.4	3039	2689
	Average	18.7	19.2	51.7	52.4	2243	2232
	SD	2.9	3.3	9.1	10.1	1015	926

N/A – data not available, instrument malfunction

Ammonia emission

For each monitored week during the two trials, ammonia concentrations were measured continuously in each room at two locations: at the ventilation inlet and at the exhaust airstream. From these ammonia readings and the corresponding ventilation rate in the room, the ammonia emission rates were calculated for each room. Table 2 summarises the weekly average ammonia concentrations and the calculated average ammonia emission rate for the two rooms. Significant levels of ammonia were measured in the incoming inlet air for both rooms; this was attributed to possible recirculation of air exhausted from the fans into the supply air coming into the barn as well as from possible back draft of ammonia from adjacent rooms into the barn attic. A paired t-test comparison of the weekly average ammonia concentrations measured at the exhaust of the two rooms showed significantly ($p<0.05$) higher mean concentration in the scraper room (11.3 ppm, SD = 2.3 ppm) than in the control room (9.8 ppm, SD = 2.1 ppm), although the mean difference was smaller than the indicated accuracy of the ammonia analyser.

In terms of ammonia emission, calculation of the percent reduction in the corresponding values (control vs. scraper) showed a mean value of –44%, indicating that ammonia emissions were higher in the scraper room compared to the control room (Table 2). This could partly be attributed to differences in ventilation rates measured in the two rooms, although the causes for the increased ammonia in the scraper room need to be investigated further.

Table 2. Summary of weekly average values for ammonia measured in the experimental (scraper) and control rooms.

	Monitored week dates	Exhaust concentration (ppm)		Inlet concentration (ppm)		Average emission (g/hr)		Emission reduction (%)
		Scraper	Control	Scraper	Control	Scraper	Control	
Trial 1	Mar8-12	10.6	7.9	3.2	3.3	13.3	8.7	-54
	Mar22-26	14.1	12.8	5.3	5.3	16.2	13.3	-21
	Apr5-9	13.1	11.7	6.6	6.6	20.9	23.4	11
	Apr19-23	7.9	7.1	3.4	3.4	22.8	19.8	-15
Trial 2	Jun28-Jul2	8.0	7.3	5.9	5.9	15.3	9.6	-59
	Jul19-23	11.7	10.6	7.7	7.7	32.3	23.2	-39
	Aug9-13	12.4	10.1	7.3	7.3	37.6	19.6	-92
	Aug23-27	13.0	10.9	7.3	7.3	41.9	23.3	-80
	Average	11.3	9.8	5.8	5.9	25.0	17.6	-44
	SD	2.3	2.1	1.8	1.7	10.9	6.2	34

Hydrogen sulfide concentrations

During each monitored week, the H_2S concentrations were measured in each room during the 15-min period that the scraper system was operated in the experimental room. However, initial results from the control room showed that measurable H_2S readings were detected only during the day that the pit plug in the room was actually pulled, while no (zero) detectable H_2S was measured in the room during days in which the pit plug was not pulled. Thus, in subsequent weeks, the H_2S levels were monitored in the control room only during the day that the pit plugged was pulled in that room. Table 3 summarises the maximum H_2S concentrations measured at the two locations in the two rooms during the day that the pit plug was pulled in the control room. The H_2S monitors were placed at two locations: over the pit plug area, and at the middle of the pit (middle pen), both at about 1 m height.

Table 3. Summary of maximum H_2S concentration (ppm) measured in the experimental (scraper) and control rooms.

	Date	Control		Scraper	
		Over plug	Middle pen	Over plug	Middle pen
Trial 1	10-Mar-04	4.0	2.0	0.0	0.0
	24-Mar-04	0.0	0.0	0.0	0.0
	7-Apr-04	9.0	0.0	11.0	7.0
	21-Apr-04	12.0	4.0	0.0	0.0
Trial 2	30-Jun-04	12.0	2.0	0.0	0.0
	21-Jul-04	95.0	N/A	6.0	N/A
	11-Aug-04	40.0	30.0	2.0	0.0
	25-Aug-04	30.0	10.0	1.0	2.0
	Average	25.3	6.9	2.5	1.3
	SD	31.2	10.8	4.0	2.6

N/A – data not available, instrument malfunction

Comparison of the corresponding values between the two rooms showed that the maximum H_2S concentrations were lower in the scraper room by an average of 80% over the plug area and by an average of 96% over the middle pen. Similarly, the 15-min TWA values were calculated for both rooms on the same monitored days and summarized in Table 4. Comparison of the values between the two rooms showed that the scraper room had 15-min TWA values lower by an average of 83% over the plug area and by an average of 99% over the middle pen. Although on few occasions the H_2S readings in the scraper room were actually higher than that in the control room, these preliminary comparisons suggest general effectiveness of the scraper system in reducing H_2S concentrations, and consequently reducing the risk of H_2S exposure of workers as well.

Table 4. Summary of 15-min TWA values for H_2S (ppm) measured from the experimental (scraper) and control rooms.

		Control		Scraper	
	Date	Over plug	Middle pen	Over plug	Middle pen
Trial 1	10-Mar-04	1.11	0.16	0.00	0.00
	24-Mar-04	0.00	0.00	0.00	0.00
	7-Apr-04	0.00	0.00	0.92	0.64
	21-Apr-04	1.59	1.03	0.00	0.00
Trial 2	30-Jun-04	2.09	0.10	0.00	0.00
	21-Jul-04	19.42	0.00	0.34	0.00
	11-Aug-04	0.02	1.42	0.02	0.00
	25-Aug-04	5.64	3.25	0.01	0.16
	Average	3.73	0.75	0.16	0.10
	SD	6.61	1.15	0.33	0.23

Additional activities

This study is still on-going; an additional trial is set to begin on September 20th, and will run until the first week of December, 2004. Data collection on a related experiment involving the separation of the manure solids and liquid components in the pit using the scraper system is also on-going and results will be reported after all trials are completed.

Conclusion

A manure scraper system was installed in a full-scale grower-finisher room in PSCI and evaluated by comparing the H_2S and ammonia levels in the room with another grower-finisher room operated under normal production conditions (control). Two trials were completed, corresponding to two production cycles for the rooms. Significant levels of ammonia were measured in the air entering both rooms, and a comparison of the weekly mean ammonia concentrations in the two rooms showed higher levels in the scraper room (11.3 ppm) than in the control room (9.8 ppm). Consequently, the weekly mean ammonia emission levels in the scraper room were higher by an average of 44% compared to the control room. The maximum H_2S concentrations measured in the scraper room were lower by an average of 80 to 96% compared to the control room. In terms of 15-min time-weighted average (TWA) values, which is a better measure of occupational exposure, the TWA values in the scraper room were on average about 83 to 99% lower compared to the control room, indicating potential effectiveness of the scraper system in reducing H_2S exposure of swine barn workers. An additional set of tests will be conducted to complete the evaluation of the scraper system.

Acknowledgements

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Evaluation of a Manure Pit Scraper System for Controlling Hydrogen Sulfide Gas in Swine Barns

Background

- Hydrogen sulfide (H_2S):
  - produced by anaerobic degradation of liquid manure
  - can have detrimental effects at high levels
- Occupational exposure limit (OEL) values:
  - 10 ppm – 8-hr time-weighted average
  - 15 ppm – ceiling OEL
- PSCI study (Chénard et al, 2003):
  - 83% of 138 manure pit plug-pulling events generated H_2S levels higher than 15 ppm

Goal, Objectives and Benefits

- Goal:
  - To design systems that will limit or prevent H_2S exposure of swine barn workers
- Specific objectives:
  - Develop a manure scraping system and evaluate for effectiveness in controlling H_2S
- Benefits:
  - Practical solutions to assist the swine industry in protecting health and safety of workers and animals

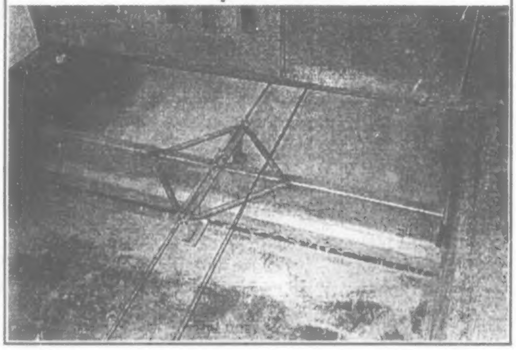
Materials and Methods

- Approach:
  - Use two identical grower-finisher rooms
  - One room with scraper system (Experimental), Second room - normal operation (Control)
- Parameters monitored:
  - H_2S, ammonia, CO_2 levels
  - Temperature, RH, ventilation rate
- Data analysis:
  - Quantify % reduction in Experimental room
  - Compare with corresponding OEL values

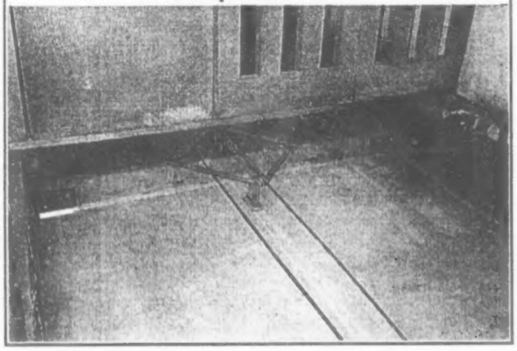
Materials and Methods

- Grower-finisher room set-up:
  - Partially slatted floors; 14.2 m x 5.4 m x 3.0 m
  - 3 sidewall fans, 6 ceiling inlets, 1 recirculation duct, 1 gas heater
  - 6 pens, 70 pigs per room, avg. 21.5 kg starting weight
- Scraper set-up:
  - Manure pit – 14.2 m x 1.8 m wide x 0.6 m deep
  - 2 pit drains (with plug) – one on each end
  - Scraper blade runs over false floor

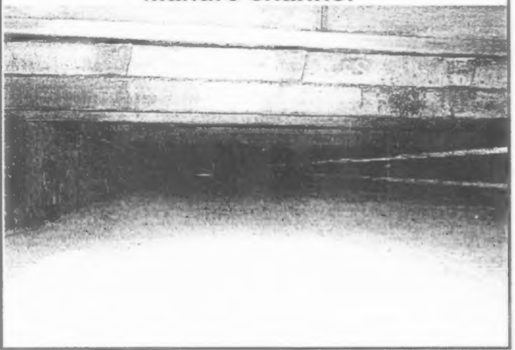
Scraper blade



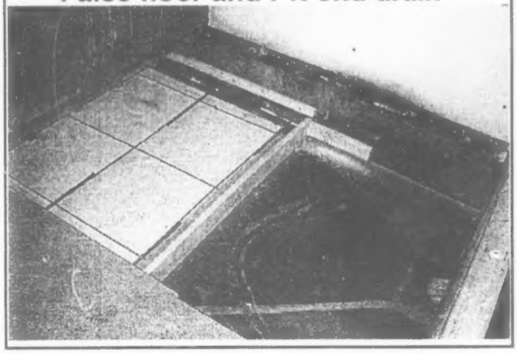
Scraper blade



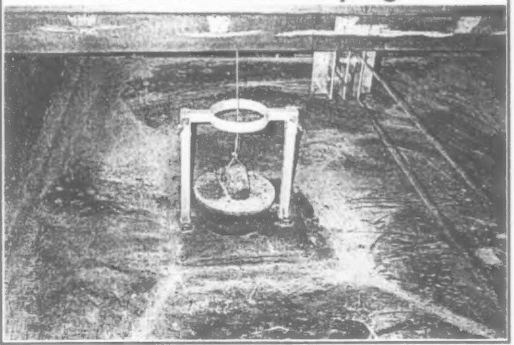
Manure channel



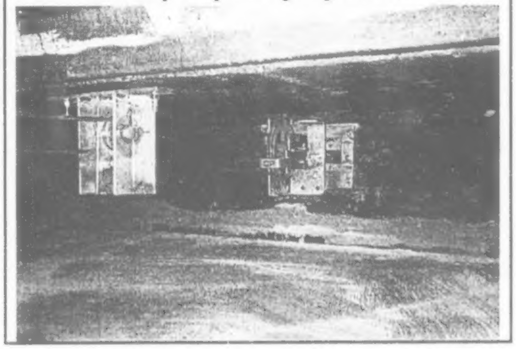
False floor and Pit end drain



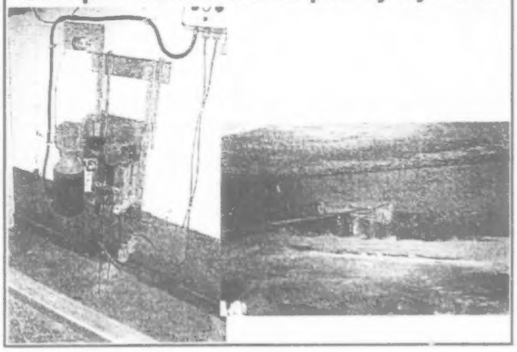
Pit end drain with plug



Scraper pulley system



Scraper controls and pulley system



Materials and Methods

- Data collection:
  - Each trial was 10 weeks
  - 4 monitored weeks (Week 4, 6, 8, 10)
  - Control – 4-week accumulation; every 2 weeks
  - Scraper – ran daily
- Instruments:
  - H_2S – Draeger Pac III monitors; 2 locations
  - Ammonia – Chillgard RT, MSA; inlet and outlet
  - Datalogger – temperature, RH, fan speed, static pressure

Results

- Summary of trials conducted:
  - Two trials completed – 8 monitored weeks
  - H_2S readings in both rooms – when plugs are pulled

Average room conditions (±SD) during the two trials.

Room parameter	Control	Scraper
Room temperature, °C	19.2 ± 3.3	18.7 ± 2.9
RH, %	52.4 ± 10	51.7 ± 9
Ventilation rate, L/s	2232 ± 926	2243 ± 1015

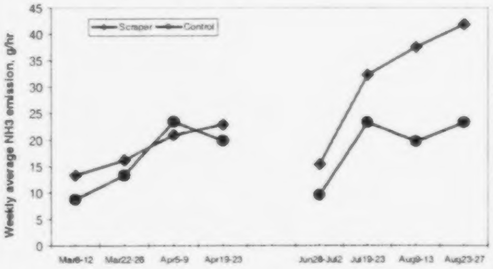
Results

- Ammonia levels:
  - Maximum ammonia concentrations - <25-ppm OEL
  - Ammonia emissions – 44% higher in scraper room

Ammonia levels (mean ± SD)	Control	Scraper
Inlet concentration, ppm	5.9 ± 1.7	5.8 ± 1.8
Exhaust concentration, ppm	9.8 ± 2.1	11.3 ± 2.3
Emission, g/hr	17.6 ± 6.2	25.0 ± 10.9

Results

- Ammonia levels: - plot of emission rates



Results

- Hydrogen sulfide levels:
  - Maximum H_2S concentrations - 15-ppm ceiling OEL
    Control – exceeded OEL three times
    Scraper – below OEL; 80 to 96% lower than Control

Max. H_2S levels (ppm ± SD)	Control	Scraper
Over plug	25.3 ± 31.2	2.5 ± 4.0
Middle pen	6.9 ± 10.8	1.3 ± 2.6

Results

- Hydrogen sulfide levels:
  - 15-min TWA values – 15-ppm STEL
    Control – exceeded STEL once
    Scraper – below STEL; 83 to 99% lower than Control

TWA H_2S levels (ppm ± SD)	Control	Scraper
Over plug	3.7 ± 6.6	0.2 ± 0.3
Middle pen	0.8 ± 1.2	0.1 ± 0.2

Conclusions

- Manure scraper system was effective in reducing hydrogen sulfide levels
  - Peak H_2S levels did not exceed OEL values
  - H_2S levels were (on average) 80 to 96% lower than Control
- Ammonia levels were higher in scraper room
  - Peak ammonia levels were still below OEL values
  - Ammonia emissions were (on average) 44% higher than Control

Additional work

- Project still on-going:
  - Third trial is underway
- Related experiment:
  - Standing water in the pit to control ammonia emission
  - Separation of solid and liquid manure components using the scraper system

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PRAIRIE
SWINE
CENTRE

Conclusions

- Manure scraper system was effective in reducing hydrogen sulfide levels
  - Peak H_2S levels did not exceed OEL values
  - H_2S levels were (on average) 80 to 96% lower than Control
- Ammonia levels were higher in scraper room
  - Peak ammonia levels were still below OEL values
  - Ammonia emissions were (on average) 44% higher than Control

Additional work

- Project still on-going
  - Third trial is underway
- Related experiment
  - Standing water in the pit to control ammonia emission
  - Separation of solid and liquid manure components using the scraper system

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Controlling hydrogen sulfide gas in swine barns with a manure pit scraper system

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Hydrogen sulfide (H_2S) gas in swine barns is produced by the anaerobic degradation of liquid manure. Most of the H_2S produced in manure pits remains dissolved in the liquid manure as long as the manure is not agitated. However, a previous study at Prairie Swine Centre Inc. (PSCI) showed that routine barn tasks such as manure pit plug-pulling and power-washing may generate elevated H_2S levels, which may potentially pose a risk to workers and animals. Hence, this study was undertaken to develop and evaluate simple engineering control measures that can be implemented in existing swine barns to reduce H_2S levels during manure handling operations. One such measure investigated was a manure pit scraper system used to remove manure daily from the manure pit.

The manure scraper system was installed in a swine grower-finisher room at PSCI. The H_2S and ammonia levels between the scraper room and an identical normal production room (control room) were compared. Initial results showed that H_2S levels in the scraper room were lower by an average of 80 to 96% compared to the control room. Additionally, maximum H_2S concentration in the scraper room did not exceed the prescribed 15-ppm occupational exposure limit (OEL), while in the control room the OEL value was exceeded three times out of eight measurements. Ammonia emissions in the scraper room were 44% higher compared to the control room. However, the average ammonia concentration in the scraper room was only about 3 ppm higher than in the control room and peak concentrations were well below the 25-ppm 8-hr OEL value for ammonia. Additional tests are on-going to complete the evaluation of the scraper system and to evaluate means to mitigate the increase in ammonia levels in the scraper room.

Implications:
This study showed that removing manure daily can effectively protect the workers and animals from potential exposure to elevated H_2S levels. A scraper system is one option for achieving daily manure removal.

Controlling Hydrogen Sulfide Gas in Swine Barns with a Manure Pit Scraper System

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Introduction

High levels of hydrogen sulfide (H_2S) can be a serious health hazard. To protect the health and safety of workers and animals, practical measures are needed to ensure that H_2S levels do not reach hazardous levels in swine barns.

Objectives

- To develop a manure pit scraper system that will remove swine manure from the barn on a daily basis, and;
- To evaluate the impact of the scraper system on H_2S concentrations and other air quality parameters in the barn.

Methods

Overall approach:

- Air quality in two grower-finisher rooms were compared over two production cycles. Each room (14.2 x 5.4 x 3.0 m) had partially slatted floors and had 70 pigs in 6 pens. Each trial lasted 12 weeks.
- A manure scraper system (Fig. 1) was used for daily manure removal from one room (Scraper). The other room (Control) had a conventional manure pit system.

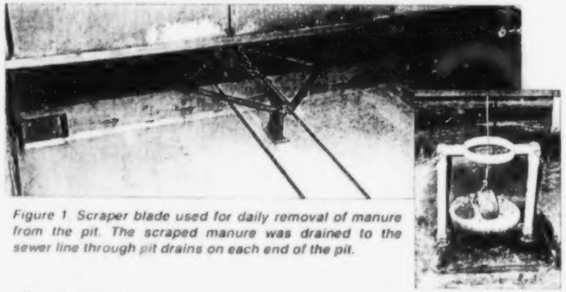

Figure 1. Scraper blade used for daily removal of manure from the pit. The scraped manure was drained to the sewer line through pit drains on each end of the pit.

Scraper set-up:

- The scraper blade (Fig. 1) can be operated in both directions using a system of pulleys and controls (Fig. 2). The scraped manure was drained through pit drains at each end of the channel (Fig. 1).

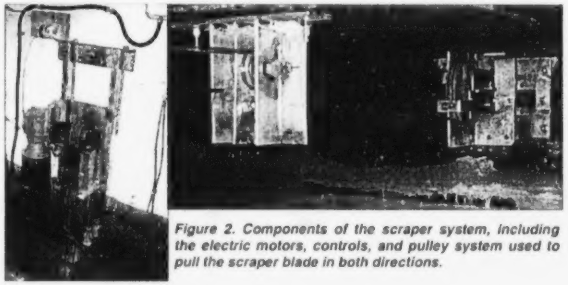

Figure 2. Components of the scraper system, including the electric motors, controls, and pulley system used to pull the scraper blade in both directions.

Data collection:

- H_2S and ammonia concentrations in both rooms were compared. Four one-week periods were monitored during each trial: weeks 4, 6, 8 and 10. The pit plug in the Control room was pulled during each monitored week.
- Two H_2S monitors (Model Pac III, Draeger, Lübeck, Germany; reproducibility of 5%) were used in each room: one over the middle pen, and another above the plug, at a height of 1 m.
- Ammonia concentrations, temperature, relative humidity, and ventilation rate were monitored continuously. Ammonia was measured using an ammonia analyser (Chillgard RT, MSA Canada; accuracy of ±2 ppm).

Results

Hydrogen sulfide concentrations:

- Preliminary results showed that maximum H_2S concentrations were lower (by at least 80%) in the Scraper room than in the Control room (Fig. 3).

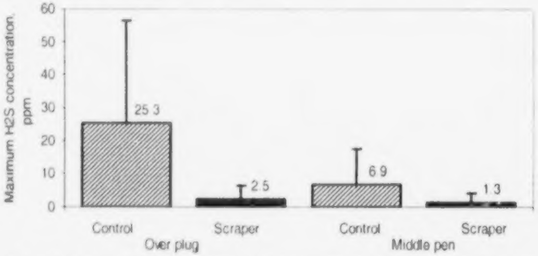

Figure 3. Comparison of maximum H_2S concentrations measured in the two rooms.

- The maximum exposure limit value of 15 ppm H_2S (AB Occupational Health and Safety Code, 2003) was exceeded three times in the Control room; no H_2S readings exceeded the limit value in the Scraper room.

Ammonia emissions:

- Mean ammonia concentration at the exhaust of the Scraper room (11.3 ppm, SD=2.3 ppm) was higher than the Control room (9.8 ppm, SD=2.1 ppm). Peak ammonia levels were below the 25-ppm NH_3 exposure limit.
- Weekly average ammonia emissions were higher in the Scraper room (25 g/hr, SD=11 g/hr) than the Control room (18 g/hr, SD=6 g/hr) (Fig. 4). Appropriate control measures are being investigated.

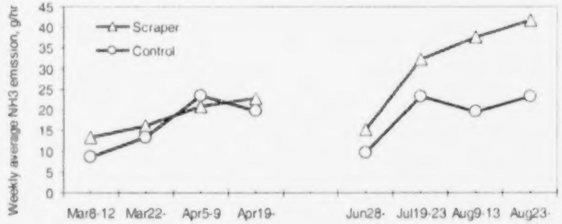

Figure 4. Comparison of average ammonia emissions from the two rooms during the two completed trials. Each data point represents average emission over one week.

Conclusions

- A manure scraper system used to remove manure daily from a swine room was effective in reducing hydrogen sulfide levels. Peak H_2S levels did not exceed maximum exposure limit for workers' safety.
- The scraper system generated higher ammonia levels, although peak ammonia levels were still below the ammonia exposure limit value. Further tests are being conducted to address this issue.

Acknowledgements

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Engineering Controls Reduce Hydrogen Sulphide Exposure in Swine Barns

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Summary

Three engineering control measures were developed and tested for effectiveness in protecting swine barn workers from exposure to hydrogen sulfide (H_2S) gas during manure handling events. A remote manure pit plug pulling system allowed the worker to pull the manure pit plug from outside the room, thereby significantly reducing risk of worker exposure to H_2S. A water sprinkling apparatus was also devised, which resulted in 79% reduction of H_2S gas concentration under optimal laboratory conditions. However, the use of a similar system on agitated manure showed the opposite effect. A manure scraper system was installed to remove manure daily from the manure pit of a grower-finisher room. Preliminary measurements showed that H_2S levels were 80 to 96% lower in the scraper room than in a similar room with a conventional pull-plug system. However, higher ammonia emissions were observed in the scraper room compared to the conventional grower-finisher room.

Introduction

High levels of H_2S can have detrimental effects on both workers and swine. Previous research by the Prairie Swine Centre Inc. (PSCI) indicated that workers are at risk of exposure to potentially hazardous H_2S levels when performing manure management tasks, such as pulling manure pit plugs. The main goal of this project is to develop practical measures that can prevent or reduce worker exposure to high H_2S concentration in swine buildings. Three different systems were investigated in separate modules.

> *"A water sprinkling apparatus resulted in 79% reduction of H_2S gas concentration under optimal conditions."*

Module 1 – Improved Design for Pit Plugs

In this module, an improved pit plug concept that allowed for pulling the plugs from a remote location was designed and evaluated. Two undergraduate students, assisted by technical staff at University of Saskatchewan and PSCI, designed and built a prototype system (Fig. 1). The system was installed in two grower-finisher rooms at PSCI and tested by measuring H_2S concentrations using a H_2S monitor (Draeger Pac III monitor with a H_2S sensor, Draeger, Lübeck, Germany) during the plug-pulling operations.

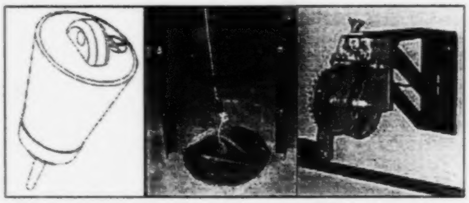

Figure 1. Improved pit-plug design showing the (a) extended cone plug, (b) with cable attached and plug-height stop, and (c) the cable-winch system for remotely pulling the plug from outside the room.

After examining several plug designs, the extended cone plug was selected and installed. Monitoring of H_2S levels during nine plug-pulling events showed that the maximum H_2S concentration in the room over the plug area was 68 ppm, while corresponding concentrations at the alleyway near the winch was 0 ppm. Hence, the system was very effective in protecting the worker from being exposed to H_2S by allowing the worker to perform the task away from the plug area.

Module 2 – H_2S Abatement by Water-based Liquid Spray

Because H_2S is water soluble, it was hypothesized that spraying a water-based liquid over agitated manure would reduce emissions into the air. In this module, a laboratory spray chamber was set up to determine the impact of a water-based spray on H_2S levels in the chamber (Fig. 2). Preliminary tests were done to investigate the reduction in H_2S levels as affected by various parameters such as type of spray nozzle, water pressure, temperature and pH, as well as the use of various chemical additives.

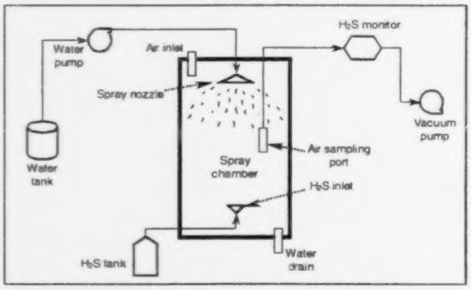

Figure 2. Schematic diagram of laboratory set-up used to determine the effect of water-based spray on H_2S levels in the chamber.

Laboratory tests with various combinations of test parameters consistently reduced the concentration of pure H_2S gas released into the chamber (Fig. 3). Using a hollow cone nozzle at 200 kPa with water at pH = 9 resulted in a 79% reduction of the peak H_2S levels. The treatment was applied to a set of barrels filled with swine manure. In four control barrels where no spray was applied, manure agitation produced an average of 148 ppm, with a peak reading of 520 ppm measured from the exhaust air. However, application of the water-spray treatment increased the average and maximum H_2S concentrations to 273 and 690 ppm, respectively. Because these were not consistent with the observations in the laboratory study, it was suspected that other gases generated in the manure barrel affected the Draeger Pac III monitor. Additional tests are ongoing to investigate the water-spray treatment further.

Module 3 – Manure Scraper System to Reduce H_2S Levels

In this module, a manure pit scraper system (Fig. 4) was installed in a grower-finisher room to remove swine manure on a daily basis. Its effectiveness was evaluated by comparing the

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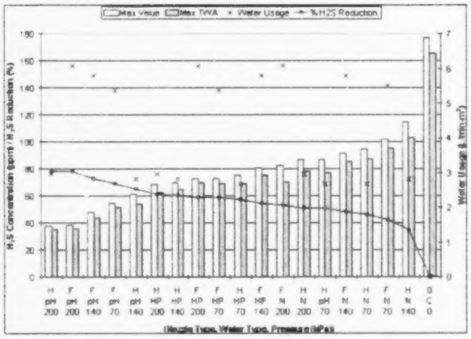

Figure 3. Summary of laboratory test results (Nozzle Types: H (hollow cone) and F (full cone); Water Type: pH (water at pH 9), HP (water with hydrogen peroxide added), and N (normal water); Pressures: 70, 140 and 200 kPa).

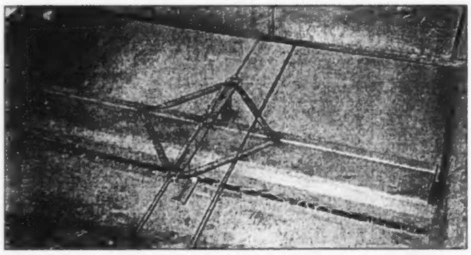

Figure 4. Scraper blade used for daily removal of manure from the pit. The manure pit has drains at both ends, through which the scraped manure was emptied to the sewer line.

air quality in the scraper room and a similar room (Control) with conventional manure pit-plug system.

The scraper system was evaluated over two production cycles; during each trial both rooms were monitored closely over four one-week periods. Table 1 summarises the maximum H_2S concentrations measured at two locations in the rooms. Compared to the control room, the maximum H_2S concentrations were lower in the scraper room by an average of 80% over the plug area and by an average of 96% over the middle pen. Additionally, the maximum H_2S levels in the control room exceeded the 15-ppm ceiling occupational exposure limit (OEL) value on three occasions during the two trials, while no peak H_2S readings were higher than this limit value in the scraper room. The ceiling OEL is the maximum concentration of a biological or chemical agent to which a worker may be exposed, i.e., no worker should be exposed to any levels above this limit at any time.

Table 1. Summary of maximum H_2S concentration (ppm) measured in the scraper and control rooms.

		Control		Scraper	
	Date	Over plug	Middle pen	Over plug	Middle pen
Trial 1	10-Mar-04	4.0	2.0	0.0	0.0
	24-Mar-04	0.0	0.0	0.0	0.0
	7-Apr-04	9.0	0.0	11.0	7.0
	21-Apr-04	12.0	4.0	0.0	0.0
Trial 2	30-Jun-04	12.0	2.0	0.0	0.0
	21-Jul-04	95.0	N/A	6.0	N/A
	11-Aug-04	40.0	30.0	2.0	0.0
	25-Aug-04	30.0	10.0	1.0	2.0
	Average	25.3	6.9	2.5	1.3
	SD	31.2	10.8	4.0	2.6

N/A – data not available, instrument malfunction

During the two trials, significant levels of ammonia were measured in the incoming inlet air for both rooms, possibly due to recirculation of air exhausted from the fans into the supply air as well as from possible back draft of ammonia from adjacent rooms into the barn attic. The weekly average ammonia concentrations measured at the exhaust was significantly ($p<0.05$) higher in the scraper room (11.3 ppm, SD = 2.3 ppm) than in the control room (9.8 ppm, SD = 2.1 ppm), although the mean difference was smaller than the indicated accuracy of the ammonia analyser. The calculated ammonia emissions were about 44% higher in the scraper room, which was attributed to the formation of a film of excreta on the pit bottom surface after scraping; this has been previously reported as possibly causing increased ammonia emissions in scraper systems. However, the observed ammonia levels were still lower than the 25-ppm OEL for ammonia, despite the presence of ammonia in the incoming air. Additional tests are on-going to determine the effectiveness of maintaining a layer of standing water at the bottom of the manure channel to control ammonia emissions.

"Preliminary measurements showed that H_2S levels were 80 to 96% lower in the scraper room."

Conclusions

A remote manure plug pulling system was successfully developed. Results showed that the system was effective in preventing worker exposure to H_2S by allowing the pulling of the plugs from the alleyway. A water-spray treatment showed consistent reduction in H_2S levels in a laboratory study. However, application of the treatment on agitated manure showed opposite effect on H_2S. A manure scraper system used for daily manure removal from a swine room was effective in reducing H_2S to levels below the maximum exposure limit for worker's safety. The system generated higher ammonia levels, although peak readings did not exceed the ammonia exposure limit value. Additional tests are being conducted to further investigate both the scraper and the water-spray systems.

Acknowledgements

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Evaluation of a Manure Pit Scraper System for Controlling Hydrogen Sulfide Gas in Swine Barns

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Summary

A manure pit scraper system was installed in a swine grower-finisher room and used to remove manure daily from the manure pit. Preliminary measurements showed that H_2S levels in the scraper room were lower by an average of 80 to 96% compared to measurements in a similar room operated under typical conditions. Additionally, maximum H2S concentration in the scraper room did not exceed the 15-ppm ceiling occupational exposure limit (OEL) while in the control room, the ceiling OEL value was exceeded three times out of eight measurements. Ammonia emissions in the scraper room were about 44% higher compared to the control grower-finisher room. However, the average ammonia concentration in the scraper room was only about 3 ppm higher than in the control room and peak concentrations were well below the 25-ppm 8-hr OEL value for ammonia.

Introduction

Hydrogen sulfide (H_2S) gas in swine barns is produced by the anaerobic degradation of liquid manure. Exposure to H_2S can have detrimental effects on both workers and swine, especially at excessively high levels (CHEMINFO, 2000). Most of the H_2S produced by anaerobic bacteria in manure pits remains dissolved in the liquid manure as long as the manure is not agitated. Results from a research project performed by Prairie Swine Centre (PSC) strongly suggest that workers are at risk of H_2S exposure while performing manure management tasks in the barn, such as pulling manure pit plugs. Out of 138 plug pulling events monitored in different barn sections, 114 events (83%) generated H_2S concentrations higher than the short-term exposure limit (STEL) value of 15 ppm (or time-weighted average concentration not to be exceeded during a 15 min exposure period, specified by Saskatchewan Occupational Health and Safety, 1996) at the worker level over the pit area. Monitoring performed during emptying of manure pits also showed that the highest H_2S concentrations measured were not necessarily restricted to the vicinity of the plug but may occur elsewhere in the room above the manure channel.

An increasing number of workers in specialized pig operations now spend more time inside the barns on a continuous basis. In some cases workers may be assigned to specific tasks related to manure management that can significantly increase their exposure to H_2S (e.g., crews assigned to power washing and pulling manure pit plugs, or those assigned to operation and maintenance of in-barn manure handling equipment). Economical and practical preventative measures need to be implemented to help ensure that the H_2S levels do not reach hazardous concentrations in swine barns to protect the health and safety of both workers and animals. A retrofit system for shallow pit in-barn manure channels to allow for more frequent and complete removal of manure from the production rooms has the potential to reduce H_2S production and emission.

Project Objectives

The overall goal of this project was to develop systems that will prevent or reduce worker exposure to high H_2S concentrations during manure handling in swine buildings. Specifically, this study aimed to develop a manure pit scraper system that will remove swine manure from the barn on a daily basis, and evaluate the impact of the system on H_2S concentrations and other air quality parameters in the barn. Ultimately, the goal was to develop a system that can be retrofitted into existing barns with liquid manure handling systems.

Figure 1. Scraper blade that was pulled over the false flooring. The manure pit has two drains, one at each end, through which the scraped manure was drained to the sewer line.

Methodology

Grower-finisher room set-up

Two commercial grower-finisher rooms at the PSC barn were used over two production cycles. Each room had partially slatted floors and was 14.2 m long, 5.4 m wide, with a 3.0 m ceiling. Three fans provided ventilation air by pulling outdoor air from the barn attic and into each room through six ceiling inlets. A forced air recirculation duct was located on one side of the room near the ceiling, and a 17.6 kW natural gas heater provided supplemental heat. The two rooms contained six pens each and were mirror images of each other. Each pen was 2.0 m wide and 4.2 m long (1/3 slatted), and had a nipple drinker and a dry feeder connected to an automatic feeding system. For this experiment, one pen remained empty throughout the trial and the other pens had 14 pigs each, for a total of 70 pigs per room. The empty pen was used to gain access to the scraper system to make adjustments as part of a separate experiment. Pigs entered the rooms at about 21.5 kg, remained in the rooms for about 12 weeks, and attained an average weight of about 96.5 kg at the end of each trial. The pigs were weighed at the beginning of each trial and sorted to ensure that the difference in the total starting weight for the two rooms was within ±1.0 kg. Pigs were fed ad libitum with commercial mash diets for grower-finisher pigs.

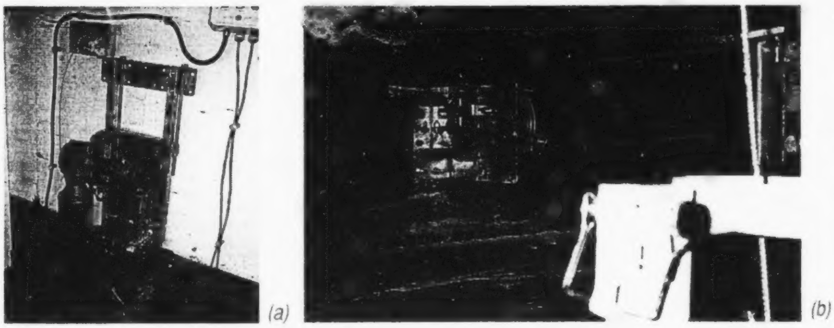

Figure 2. Components of the scraper system including the (a) electric motor, controls, and (b) pulley system used to pull the scraper blade in both directions.

In one of the rooms (Experimental), the manure scraper system was installed and operated daily, while the other room (Control) was operated normally, i.e., manure was allowed to accumulate in the pits and the pit plugs were pulled on a predetermined schedule.

Scraper set-up

The manure scraper system was assembled and installed in the manure pit of the experimental (scraper) room. The main components of the scraper system were obtained from a commercially-available system manufactured in Québec, where such systems are used in some swine operations and in other livestock (dairy) industries (Figs. 1 & 2). The manure channel in the room was 14.2 m long, 1.8 m wide and 0.6 m deep, with a pit drain at each end. To ensure complete drainage of the manure when the scraper was operated, a false floor was laid on the manure channel bottom surface to raise the manure pit floor by 0.25 m at one end, which gradually sloped down to 0.20 m on the other end. The scraper blade, which can be operated in both directions, ran over the false floor surface (Fig. 1), although it did not cover the entire length of the manure channel. It stopped at about 1.1 m from one drain on one end and about 1.6 m from the drain on the other end, thus leaving an area around the drain where manure accumulated. Two manure tubs were built out of mild steel and one was placed at each end of the false floor. All sides of this tub were sloped toward the pit drain (with a pit plug) at its center, to ensure complete drainage of manure into the drain hole when the plug was pulled and to prevent retention of any manure from which H_2S could be produced (Fig. 3).

The scraper system was operated daily, dropping the solids from the false flooring into the accumulation pit, after which the plug was immediately pulled to let the manure drain as a slurry mixture.

Data Collection

The room air quality and H_2S concentrations in the experimental (scraper) room were compared to an identical room with conventional plugs (control) over two production cycles. Four one-week periods were monitored over each production cycle: weeks 4, 6, 8 and 10, which comprised one trial. The pit plug in the control room was pulled in the middle of each of the one-week monitored periods. The schedule of monitoring was set to coincide with normal plug pulling schedules in the rooms, which allowed for manure to accumulate initially over a 4-week period while the pigs were small, while subsequent tests were done after every two weeks to account for larger manure production as the pigs grew larger. For each scraping and pulling event during the monitored week, two H_2S monitors (Model Pac III, with XS EC 1000 ppm H_2S sensor, Draeger, Lübeck, Germany) were installed in each room: one over the middle of the manure pit (middle pen) and another directly above the plug, both approximately 1 m off the floor. The H_2S monitors, which recorded H_2S readings at 10-sec sampling intervals, were started five minutes before pulling the plug. Preliminary tests were done to determine the length of time that the pit drains need to remain open for the slurry to drain completely (10 min), since leaving the drain open longer than necessary could allow a back draft of H_2S to the room from the sewer line. After the plug was replaced, the monitor continued collecting data for another 5 min to obtain H_2S measurements both before and after the pulling event.

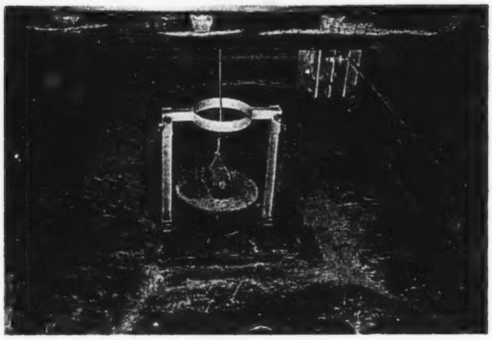

Figure 3. Pit drain with a pit plug located in the middle of the accumulation tub. At each end of the pit, a sloping tub was installed to facilitate clearing the scraped manure into the pit drain.

In the experimental room, the scraper system was operated daily and the pit plug was remotely pulled daily as well. The H_2S monitors were operated in similar manner as in the control room: monitors were started five minutes before scraping the channel, plug was pulled after scraping and the plugs remained open for 10 min, the plug was replaced, and the monitor continued collecting data for another 5 min after replacing the plug.

The air quality in both rooms was measured on a continuous basis during the monitored week. Ammonia concentrations were measured at the inlet and outlet of both rooms using a sampling manifold system attached to an ammonia analyser.

Preliminary results

Summary of trials

Two trials were completed from March 8 to August 27, 2004, corresponding to two production cycles. Table 1 summarises the weekly average values for temperature and relative humidity in the two rooms. Outdoor ambient conditions during the first three weeks of Trial 1 were cold, thus the ventilation rates in both rooms were lower compared to the rest of the trials. In general, nearly similar conditions were maintained in both rooms throughout the trials, as can be observed from the close mean values for temperature, RH and ventilation rates measured in the two rooms (Table 1).

Ammonia emissions

Table 2 summarizes the weekly average ammonia concentrations and the calculated average ammonia emission rate for the two rooms. Significant levels of ammonia were measured in the incoming inlet air for both rooms; this was attributed to possible recirculation of air exhausted from the fans into the supply air coming into the barn as well as from possible back draft of ammonia from adjacent rooms into the barn attic.

Continued on page 6

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In terms of ammonia emission, calculation of the percent reduction in the corresponding values (control vs. scraper) showed an average reduction of –44%, indicating that ammonia emissions were higher in the scraper room compared to the control room (Table 2).

It is well documented that scraper systems can promote ammonia emissions by leaving a film of excreta at the bottom of the channel. In this regard, data is being concurrently collected from the set-up as part of a related study to determine the effectiveness of maintaining a layer of standing water at the bottom of the manure channel to control these emissions. Results of this study will be reported after all the trials are completed.

From a health and safety perspective, the increase in ammonia production rate in the scraper room did not compromise the worker safety. The average ammonia concentration in the scraper room was no more than 3 ppm higher than in the control room, with a maximum concentration of 22.6 ppm measured during Week 2 of Trial 2 (17.1 ppm in the control room). Compared to 25 ppm concentration normally used for the 8-hr occupational exposure limit (OEL) for ammonia (Alberta Occupational Health and Safety Code, 2003), the scraper room concentrations were still lower than this limit value, despite the presence of ammonia in the incoming air.

Table 1. Summary of weekly average values for temperature. relative humidity and ventilation rates measured in the experimental (scraper) and control rooms.

	Monitored week dates	Average room temperature (°C)		Average relative humidity (%)		Average ventilation rate (L/s)	
		Scraper	Control	Scraper	Control	Scraper	Control
Trial 1	Mar8-12	18.3	18.3	48.5	N/A	768	808
	Mar22-26	16.4	16.3	52.2	51.5	881	859
	Apr5-9	15.5	16.2	43.5	43.8	1661	2111
	Apr19-23	16.1	16.4	37.9	36.6	2310	2382
Trial 2	Jun28-Jul2	23.1	23.9	47.2	49.5	3035	2938
	Jul19-23	22.8	23.4	63.1	63.0	3230	3208
	Aug9-13	19.6	21.8	58.9	59.0	3022	2858
	Aug23-27	17.7	17.3	62.1	63.4	3039	2689
	Average	18.7	19.2	51.7	52.4	2243	2232
	SD	2.9	3.3	9.1	10.1	1015	926

N/A – data not available, instrument malfunction

Table 2. Summary of weekly average values for ammonia measured in the experimental (scraper) and control rooms.

	Monitored week dates	Exhaust concentration (ppm)		Inlet concentration (ppm)		Average emission (g/hr)		Emission reduction
		Scraper	Control	Scraper	Control	Scraper	Control	(%)
Trial 1	Mar8-12	10.6	7.9	3.2	3.3	13.3	8.7	-54
	Mar22-26	14.1	12.8	5.3	5.3	16.2	13.3	-21
	Apr5-9	13.1	11.7	6.6	6.6	20.9	23.4	11
	Apr19-23	7.9	7.1	3.4	3.4	22.8	19.8	-15
Trial 2	Jun28-Jul2	8.0	7.3	5.9	5.9	15.3	9.6	-59
	Jul19-23	11.7	10.6	7.7	7.7	32.3	23.2	-39
	Aug9-13	12.4	10.1	7.3	7.3	37.6	19.6	-92
	Aug23-27	13.0	10.9	7.3	7.3	41.9	23.3	-80
	Average	11.3	9.8	5.8	5.9	25.0	17.6	-44
	SD	2.3	2.1	1.8	1.7	10.9	6.2	34

Hydrogen Sulfide Concentrations

During each monitored week, the H_2S concentrations were measured in each room during the 15-min period that the scraper system was operated in the experimental room. However, initial results from the control room showed that measurable H_2S readings were detected only during the day that the pit plug in the room was actually pulled, while no (zero) detectable H_2S was measured in the room during days in which the pit plug was not pulled. Thus, in subsequent weeks, the H_2S levels were monitored in the control room only during the day that the pit plug was pulled in that room. Table 3 summarises the maximum H_2S concentrations measured at the two locations in the two rooms during the day that the pit plug was pulled in the control room. The H_2S monitors were placed at two locations: over the pit plug area, and at the middle of the pit (middle pen), both at about 1 m height.

Table 3. Summary of maximum H_2S concentration (ppm) measured in the experimental (scraper) and control rooms.

		Control		Scraper	
	Date	Over plug	Middle pen	Over plug	Middle pen
Trial 1	10-Mar-04	4.0	2.0	0.0	0.0
	24-Mar-04	0.0	0.0	0.0	0.0
	7-Apr-04	9.0	0.0	11.0	7.0
	21-Apr-04	12.0	4.0	0.0	0.0
Trial 2	30-Jun-04	12.0	2.0	0.0	0.0
	21-Jul-04	95.0	N/A	6.0	N/A
	11-Aug-04	40.0	30.0	2.0	0.0
	25-Aug-04	30.0	10.0	1.0	2.0
	Average	25.3	6.9	2.5	1.3
	SD	31.2	10.8	4.0	2.6

N/A – data not available, instrument malfunction

Comparison of the corresponding values between the two rooms showed that the maximum H_2S concentrations were lower in the scraper room by an average of 80% over the plug area and by an average of 96% over the middle pen. From a health and safety point of view, the maximum H_2S levels in the control room exceeded the 15-ppm ceiling OEL value (Alberta Occupational Health and Safety Code, 2003) on three occasions during the two trials, while no peak H_2S readings were higher than this limit value in the scraper room. The ceiling OEL is the maximum concentration of a biological or chemical agent to which a worker may be exposed at any time, i.e., no worker must be exposed to any levels above this limit for any period of time.

Similarly, the 15-min TWA values were calculated for both rooms on the same monitored days and summarized in Table 4. Comparison of the values between the two rooms showed that

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Table 4. Summary of 15-min TWA values for H_2S (ppm) measured from the experimental (scraper) and control rooms.

		Control		Scraper	
	Date	Over plug	Middle pen	Over plug	Middle pen
Trial 1	10-Mar-04	1.11	0.16	0.00	0.00
	24-Mar-04	0.00	0.00	0.00	0.00
	7-Apr-04	0.00	0.00	0.92	0.64
	21-Apr-04	1.59	1.03	0.00	0.00
Trial 2	30-Jun-04	2.09	0.10	0.00	0.00
	21-Jul-04	19.42	0.00	0.34	0.00
	11-Aug-04	0.02	1.42	0.02	0.00
	25-Aug-04	5.64	3.25	0.01	0.16
	Average	3.73	0.75	0.16	0.10
	SD	6.61	1.15	0.33	0.23

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the scraper room had 15-min TWA values lower by an average of 83% over the plug area and by an average of 99% over the middle pen. Furthermore, the 15-min TWA values for the scraper room were generally less than 1 ppm and did not exceed the short-term exposure limit (STEL) value of 15 ppm H_2S during the two trials. The corresponding values in the control room had an average of about 3.7 ppm, with one measurement exceeding the STEL value. Although on few occasions the H_2S readings in the scraper room were actually higher than that in the control room, these preliminary comparisons suggest general effectiveness of the scraper system in reducing H_2S concentrations, and consequently reducing the risk of H_2S exposure of workers as well.

The Bottom Line

Scrapers installed in the pit under the slats increased ammonia concentrations in the air. This may be mitigated through use of water film, and this is under investigation.

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Tips for Saving Water

Water is an essential nutrient in pork production. Research reveals how we can manage this resource for best results and minimal cost.

1. **Do a water audit.** Wasted water costs money to pump and to dispose of in slurry. The average usage is 78L per sow (farrow to finish farm), however actual usage has been reported as low as 65L/sow and as high as 120L/sow, a variation of as much as 50% from the mean! See water usage table in Pork Production Reference Guide 2000, pg 30.

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the evaporation of urine and fecal material can be accomplished by ensuring proper dunging patterns are maintained by properly monitoring inlets and recirculation ducts as well as regular cleaning of pens. Clean pens will also reduce the level of ammonia in the room. Ammonia is produced by the decomposition of nitrogenous compounds in feces and urine on solid surfaces. At the time of manure removal from the room hydrogen sulfide is released and only at this time should the ventilation rate be increased to reduce hydrogen sulfide levels. Dust levels can be reduced in a facility by minimizing feed handling and disturbance and by avoiding disturbing the pigs. Proper safety equipment should also be available to staff including dust masks, eye and hearing protection.

Regular maintenance on ventilation equipment is important to ensure proper ventilation rates are maintained during the winter months. All fans need to be cleaned and function properly. As cold season arrives proper fan covers should be installed on all stages of fans not utilized during the winter months. These covers should be maintained so that they maintain their insulation value and do not allow the back drafting of cold air into the facility. All fan hoods should be mounted to ensure wind protection for exhaust fans so that wind pressure against the fan will not cut off the fan air delivery. Air inlet adjustment is also very important to the ventilation system during the heating season. The opening size should comply with the minimum ventilation rate to ensure more cold air is not entering the room requiring excess heating. Inlet opening controls and actuators should be monitored to ensure proper functioning at all times. Heaters should also be checked and serviced regularly. Corrosion of relay contact points is very common and the pilot of gas heaters should be kept clean.

The Bottom Line

After a ventilation system is designed it is very important to ensure the proper management of the system. It is recommended to draw up procedures for all seasons to ensure that the ventilation system can be properly monitored on the following basis:

- setpoint temperatures
- minimum ventilation rates during heating seasons
- fan scheduling
- air inlet adjustment
- moisture control
- odour and dust control

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In terms of ammonia emission, calculation of the percent reduction in the corresponding values (control vs. scraper) showed an average reduction of –44%, indicating that ammonia emissions were higher in the scraper room compared to the control room (Table 2).

It is well documented that scraper systems can promote ammonia emissions by leaving a film of excreta at the bottom of the channel. In this regard, data is being concurrently collected from the set-up as part of a related study to determine the effectiveness of maintaining a layer of standing water at the bottom of the manure channel to control these emissions. Results of this study will be reported after all the trials are completed.

From a health and safety perspective, the increase in ammonia production rate in the scraper room did not compromise the worker safety. The average ammonia concentration in the scraper room was no more than 3 ppm higher than in the control room, with a maximum concentration of 22.6 ppm measured during Week 2 of Trial 2 (17.1 ppm in the control room). Compared to 25 ppm concentration normally used for the 8-hr occupational exposure limit (OEL) for ammonia (Alberta Occupational Health and Safety Code, 2003), the scraper room concentrations were still lower than this limit value, despite the presence of ammonia in the incoming air.

Hydrogen Sulfide Concentrations

During each monitored week, the H_2S concentrations were measured in each room during the 15-min period that the scraper system was operated in the experimental room. However, initial results from the control room showed that measurable H_2S readings were detected only during the day that the pit plug in the room was actually pulled, while no (zero) detectable H_2S was measured in the room during days in which the pit plug was not pulled. Thus, in subsequent weeks, the H_2S levels were monitored in the control room only during the day that the pit plug was pulled in that room. Table 3 summarises the maximum H_2S concentrations measured at the two locations in the two rooms during the day that the pit plug was pulled in the control room. The H_2S monitors were placed at two locations: over the pit plug area, and at the middle of the pit (middle pen), both at about 1 m height.

Table 1. Summary of weekly average values for temperature, relative humidity and ventilation rates measured in the experimental (scraper) and control rooms.

	Monitored week dates	Average room temperature (ºC)		Average relative humidity (%)		Average ventilation rate (L/s)	
		Scraper	Control	Scraper	Control	Scraper	Control
Trial 1	Mar8-12	18.3	18.3	48.5	N/A	768	808
	Mar22-26	16.4	16.3	52.2	51.5	881	859
	Apr5-9	15.5	16.2	43.5	43.8	1661	2111
	Apr19-23	16.1	16.4	37.9	36.6	2310	2382
Trial 2	Jun28-Jul2	23.1	23.9	47.2	49.5	3035	2938
	Jul19-23	22.8	23.4	63.1	63.0	3230	3208
	Aug9-13	19.6	21.8	58.9	59.0	3022	2858
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	SD	2.9	3.3	9.1	10.1	1015	926

N/A – data not available, instrument malfunction

Table 2. Summary of weekly average values for ammonia measured in the experimental (scraper) and control rooms.

	Monitored week dates	Exhaust concentration (ppm)		Inlet concentration (ppm)		Average emission (g/hr)		Emission reduction
		Scraper	Control	Scraper	Control	Scraper	Control	(%)
Trial 1	Mar8-12	10.6	7.9	3.2	3.3	13.3	8.7	-54
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	21-Apr-04	12.0	4.0	0.0	0.0
Trial 2	30-Jun-04	12.0	2.0	0.0	0.0
	21-Jul-04	95.0	N/A	6.0	N/A
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